THE MARINE DISPOSAL OF SEWAGE SLUDGE AND
DREDGE SPOIL IN THE WATERS OF THE NEW YORK BIGHT

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Report to the Coastal Engineering Research Center,
Corps of Engineers, U.S. Department of the Army

January 29, 1971

Contract DACW72-70-C-0030

7-(7)

ABSTRACT

The dumping of sewer sludge and dredge spoil in the waters of the New York Bight and the effect of this waste disposal practice on the marine environment is reviewed. The quantities and composition of these wastes is described together with their physical, chemical and biological effects on the environment. At the center of the sludge dump the bearing capacity of the waters has been exceeded and an anoxic bottom area devoid of life formed. Both spoil and sludge contain large quantities of toxic heavy metals and the spoil also contains large quantities of petrochemicals and pesticides.

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I

INTRODUCTION

In 1924 a sewer sludge dumping ground was established in the New York Bight off Ambrose Light about equidistant (12 miles) from the Long Island and New Jersey shorelines. In accordance with the Refuse Act of the previous century which assigns responsibility of protecting navigable waters to the U.S. Army Corps of Engineers, the Corps was given the authority to issue permits for waste disposal in this area. Subsequently, the number of separate waste disposal grounds in the New York Bight area grew to five (Figure 1).....one each for sewer sludge, dredge spoil, celler dirt, acid waste, and toxic chemicals (Figure 2 shows some of the sites and quantities involved, both in the New York Bight and Long Island Sound waters).

Until recently, there has been little concern with the possible deleterious effects of these dumping activities on the marine environment. "Out of sight, out of mind" has been an accurate description of the attitude of both the public and of responsible officials towards these dumps. In 1959, after 20 years of dumping operations the Director of the Division of Sewage Disposal, N.Y.D.P.W., reported that "complaints of nuisance are minimal" and most of these complaints were of the stink resulting from sludge loading operations (O'Leary, 1959). In fact, even in the last year an article appearing in Science on "Environmental Protection in the City of New York" (Eisenbud, 1970) failed to mention dumping in the New York Bight and the pollution problems arising therefrom.

This attitude has not been entirely unjustified. While there has been very little work on the effects of sludge and spoil dumping at sea (Beyer, 1955; Saila, 1968; Ronin, et.al., 1967), sewer outfalls have been carefully investigated and these studies point to the rather surprising conclusion that such outfalls if properly designed do not constitute serious threats to the environment. The very massive Hyperion Plant (Los Angeles) sewer sludge pipeline outfall in 20 years of operation has apparently done remarkably little damage to the marine environment (Hume, et.al., 1962). A British investigator reports that human disease contracted by swimming in sewage-polluted sea water is rare (Moore, 1960), in fact, if the waters are aesthetically acceptable they are probably safe!

Nevertheless, from time to time there have been hints that all was not well in the waters of the Bight and there have even been occasional expressions of concern. In 1931, the disposal of garbage and other floatable refuse at sea was stopped by a U.S. Supreme Court injunction obtained against the City of New York by the State of New Jersey and in the late 1940's sport and commercial fishermen in New York and New Jersey fought a long and bitter fight to prevent the establishment of the acid waste dumping grounds. In 1966, a U.S. Public Health Service preliminary study (Buelor, et.al., 1968) revealed high coliform levels in sludge samples destined for the Bight collected at the treatment plants.

As public concern with the deterioration of the environment grew, the Corps of Engineers, aware that it was among those government agencies which most profoundly effects the environment, and mindful of its responsibilities of protecting the environment, even although these responsibilities remain legally ill-defined, became concerned with the possible environmental consequences of the enormous dumping operations in the waters of the Bight and in addition to a study undertaken by the Sandy Hook Marine Laboratory requested the Smithsonian Institution to review and investigate the matter.

In February 1970 the issue became headlines when, on the basis of preliminary results obtained by the Corps-sponsored studies, then Congressman R.L. Ottinger accused the Corps of permitting the formation of a 20mi^2 "dead sea" in the waters of the New York Bight (Peter, 1970).

"The New York Harbor Complex is the largest grossly polluted area in the United States, if not the world" (Ad Hoc Committee, 1970), but far from being a local problem, the environmental effects of the ocean dumping of sludge, spoil and other wastes is a matter of the gravest national concern for it is abundantly clear the burgeoning coastal population concentrations will increasingly resort to ocean disposal for getting their refuse out of sight and out of mind. The New York Bight is but only the worst and the first unless suitable legal and technological safeguards are applied.

II

THE WATERS OF THE NEW YORK BIGHT

A. Topography

The topography of the New York Bight is shown in Figure 3. The water depth in the sludge dump is approximately 70ft, in the spoil dump about 60ft. (King, 1970). For the most part the topography is typical of the Continental Shelf. The most prominent topographical feature of the area is the head of the Hudson Canyon. In the Canyon the water depth increases to as much as 240ft. (Ketchum, et.al., 1951). Because of its ecological importance, fears have been expressed that the pollution from the dump areas might spread into the Canyon (Peter, 1970). On the other hand, the lack of damage to benthic life by the Hyperion outfall mentioned above may be largely due to the disappearance of the material into a nearby submarine canyon. The possibility of removing the present dump grounds to the canyon is worthy of objective consideration.

Uncontaminated sediments in the New York Bight area consist of sand with an organic content of less than 5% of the dry weight of the sediment (Ketchum, 1970a). Sediments along the New Jersey coast in waters up to 60ft. in depth are moderately coarse sands and in some instances gravels. These coarse coastal sands grade into medium sands in waters 60 to 90ft. deep and into fine sands in waters 90ft. or deeper (Pearce, 1969). Little river-borne sediment finds its way to the North Atlantic at the present time (Emery, 1968; Meade, 1969) and most of that transported to the N.E. coast of the United States is retained by estuaries (Meade, 1969) unless removed by dredging. Thus, despite the high turbidity of the waters, in the New York Bight there is little natural sedimentation to dilute or bury waste solids.

The effect of dumping on bottom materials is discussed in a subsequent section (IV-A).

B. Currents

The single most important oceanographic parameter determining the environmental effects of marine dumping is the currents-system in the dump and adjacent areas. The currents together with the oxygen content of the waters (which in turn is determined largely by currents and mixing) fix the maximum load or capacity of the dump area.

Fortunately the currents in the Bight are strong. The waters of the grossly polluted Hudson River rarely exceed 1% of the total water since strong horizontal ocean circulation flushes the 500mi^2 of the Bight every 6-10 days (Ketchum, et.al., 1951; Ketchum, 1970b). But unfortunately, the circulation pattern is a complex one with seasonably fluctuating eddies and the direction of the currents is frequently onshore. Thus even the strength of the currents is a partial liability for it tends to bring polluting material towards shore giving it less chance to decompose in addition to spreading the polluted area.

Figures 4-7 summarize the seasonal variations in surface currents along a section of the Atlantic seaboard including the Bight while Figure 8 shows the complicated patterns of onshore eddies. Surface drifters released in the month of February in the dump areas as part of the Sandy Hook Laboratory study were not recovered indicating that in the winter months prevailing NW winds produce offshore currents (Pearce, 1969) in accord with the earlier observations of Bumpus and Lauzier (1965). However, in the summer a southwest current developes with a northerly current along the Long Island coast. The surface current tendency is then onshore and drift bottles released in the dumping area return along the Long Island and to a lesser extent New Jersey shores (Figure 9).

More relevant to the problems of the dump areas as sources of pollution are the bottom currents. These are generally strong and northerly at all times and bottom drifters released in the sludge dump in time end up along the beaches of Long Island (Figures 10 and 11).

The Sandy Hook Laboratory is also measuring current velocities, but at the time of this writing these important data have not yet been released.

As for waters adjacent to the Bight, Marmer (1935) has described the tides and currents of New York Harbor, Riley (1952) the salinity distribution and currents in Long Island Sound, and Figure 12 shows the net current patterns in Raritan and Lower Bays.

In conclusion, Ketchum (1970b) has testified that "....The location of the sewage sludge dump in the New York Bight is indeed one of the worst that could be selected in the coastal areas". The currents are largely onshore and 40% of the sea-bed drifter devices released in the contaminated area return to shore.

C. Physical-Chemical Properties of the Waters

Both temperature and salinity of the Bight waters vary on a seasonal basis (Figure 19). In the winter, the waters are characterized by a vertical homogeneity. The coldest and least saline water is close to the shore, with warmer and more saline water offshore. A tongue of this warmer ocean water is found along the Hudson Canyon. The temperature reaches a low around $0^{o}C$ onshore and $5^{o}C$ offshore. The salinity varies from $31^{o}/oo$ to $34^{o}/oo$ offshore, with lower salinities at the mouth of the Hudson River (Figures 13-19).

In the spring, large quantities of warmer fresh water enter the Bight from the Hudson River. This water tends to stay on the surface and sets up a vertical inhomogeneity, and the beginning of the thermocline. The difference between bottom and surface temperatures at this time is about 4^{o}C. The surface temperature in April varies from under 7^{o}C to over 8^{o}C. The salinities vary from 20^{o}/oo - 25^{o}/oo at the Hudson River mouth to 32^{o}/oo offshore.

The summer is characterized by the establishment of a thermocline. The surface temperatures vary around 22-25^{o}C, and the bottom temperature varies from lows under 10^{o}C in the Hudson Canyon to 20^{o}C. The difference between surface and bottom temperature varies from 5^{o}-6^{o}C at the river mouth to over 10^{o}C offshore and over the Hudson Canyon. The surface salinity varies from 25^{o}/oo to 32^{o}/oo, with the lowest readings at the river mouth. The bottom salinity varies from 28^{o}/oo to over 32^{o}/oo offshore. The differences range from 3^{o}/oo at the river mouth to quite small differences well offshore.

Autumn sees the re-establishment of the winter pattern. Water temperature drops, and salinity increases as river flow decreases. The coldest water is again found onshore. The salinities vary from 27^{o}/oo to 33^{o}/oo, and the temperatures from 10^{o}C - 15^{o}C. Figure 19 shows the seasonal variation at two stations in the Bight.

The very recent Sandy Hook Laboratory studies found in general low salinity surface waters moving from the harbor to the southeast. June surface and bottom salinities are compared in Figures 20 and 21, and the seasonal variations in surface and bottom temperatures in Figure 22. The surface temperature has a low in March, a peak in June or July followed by a sharp drop in July - August and rises to another high in September - October. During the summer, the Bight is touched by the edge of an enormous cold cell that can cause rapid changes in bottom temperature (Pearce, 1969).

The importance of the oxygen content of the waters in decomposing waste material was mentioned briefly above and will be dealt with in detail later (Sections III-D and IV-B). It should be noted that the oxygen values shown in Figure 13, 14, 17, 18, and 19 are those of the Bight waters nearly 20 years ago prior to pollution on a massive scale....in a sense they represent the "normal" condition of the waters.

The annual cycle of nutrients such as phosphorus and nitrogen has been examined in some detail in the waters adjacent to the Bight to the east during the years 1956-1958. In surface waters the nitrate - nitrogen is sometimes completely exhausted even although small concentrations of phosphorus are always present. The N:P ratio varies from zero to 10. During the summers vertical mixing supplies N and P to the euphotic zone. The N:P ratio in deep offshore waters is about 12:1 and there is little seasonal variation in concentrations at the oxygen-maximum - nutrient-maximum layer.

TABLE 1

Maximum Concentrations of Inorganic Phosphorus and Nitrate-Nitrogen in µG-AT/l at STS, G, H and J (deep waters)

Date	Phosphorus	Nitrogen	N:P(atoms)
February, 1957	1.86	20.8	11.2
March, 1957	1.72	19.8	11.5
July, 1957	1.63	20.0	12.3
September, 1957	1.64	18.2	11.1
November, 1957	1.52	18.8	12.4
January, 1958	1.54	22.5	14.6
March, 1958	1.67	24.2	14.5
May, 1958	1.62	21.4	13.2
Mean	1.65	20.7	12.5
Standard deviation	0.11	1.97	--

(Ketchum, Vaccaro and Corwin, 1958)

Even prior to the growth of the dumping areas the waters of the Bight contained a great deal of suspended material as one might expect at the mouth of so considerable a river as the Hudson. Transparency values measured in July-September, 1951 ranges from less than 10 feet (white Secchi disk) in the outer harbor to about 50 to 60 feet in the area of the present dumps.

D. Resource Value

Finally, in this section describing the New York Bight area we would like to say some words as to its value as a natural resource. This resource value is of the utmost importance for in the last analysis it is this value which must be weighed against the necessity of waste disposal. Unfortunately, it is extremely difficult if not impossible to assess the value for such intangible qualities as aesthetics and psychological and sociological effects of good or bad environment make very large contributions to it. Even such more concrete data as the number of persons enjoying that resource - fishing, boating, swimming, and just looking at the sea - is difficult to come by, let alone the quality of that enjoyment. Furthermore, we are almost entirely ignorant of the real extent of the damage that our disposal activity is doing, particularly long range future damage,

Here we will confine our attention to only two resource values of the Bight area - fisheries and the proposed Gateway National Recreation Area.

The damage suffered by U.S. fisheries by pollution is enormous. Of an estimated 1969 potential shellfish catch of $320,000,000 it is estimated that about 1/5th or $63,000,000 is lost due to pollution (Train, Cahn and MacDonald, 1970).

In 1969, New York fish and shellfish landings, excluding unclassified fish for reduction amounted to 40,800,000 lbs valued at $14,000,000 (Table 2). There are in addition other potential commercial fishery resources such as the deep water crab (Geryon quinquedens) which have yet to be exploited (Schroeder, 1959). As we shall see (Section IV-C) it is most unclear what effect if any dumping in the Bight is having on this resource and the situation is further confused by the fact that the United States is not highly dependent upon its own fisheries and has let the industry deteriorate. The unsettling thought is that if we continue our pollution of marine waters, this resource may not be there in the future when we need it.

The pollution of the New York Bight poses a potential threat to the proposed Gateway National Recreation Area - a new major conservation effort, designed to bring parks to the people - which is expected to serve 55,000,000 visitors/yr. The philosophy behind the project which addresses itself to the amelioration of the deteriorated urban environment derived from the clear need to improve the life quality of the urban poor and near-poor, and as such the success or failure of the program will have the most profound effect on the social fabric and political stability of our nation.

A 1968 FWPCA survey in connection with the project found NO demonstrable connection between ocean disposal and water pollution at the proposed park locations while urging the need for further study. However, it does conclude that beaches are and will be closed to swimming because of pollution from other sources. It has been suggested (Ad hoc Committee, 1970) that unsubstantiated reports of pollution from dumping will cause many people to avoid ocean beaches in favor of much more seriously polluted beaches inside the harbor.

TABLE 2

SPECIES	TOTAL			
	1969		1968	
FISH	POUNDS	VALUE	POUNDS	VALUE
ANGLERFISH.	25,400	$1,212	22,025	$909
BLUEFISH.	1,119,432	131,950	576,287	116,767
BONITO.	18,465	1,108	25,962	1,582
BUTTERFISH.	763,376	110,132	974,018	150,574
COD	448,996	61,785	364,344	46,131
EELS: COMMON	168,188	39,306	140,428	31,677
CONGER	200	24	100	4
FLOUNDERS:				
GRAY SOLE	15,502	1,640	15,214	1,545
LEMON SOLE.	700	73	4,900	720
BLACKBACK	1,616,927	97,477	1,825,533	106,507
YELLOWTAIL.	4,698,659	376,251	5,614,991	413,083
FLUKE	573,420	200,261	1,215,742	396,534
HADDOCK	20,050	2,712	14,445	1,739
HAKE: RED (LING) . .	253,109	14,873	349,055	20,518
WHITE.	4,850	485	2,600	260
HERRING, SEA.	132,870	8,652	96,924	8,874
KING WHITING (KINGFISH)	12,483	2,157	20,018	2,343
MACKEREL.	491,771	32,519	810,323	50,116
MENHADEN.	9,762,457	229,940	17,784,755	193,784
POLLOCK	2,980	197	6,600	386
SCUP OR PORGY	1,637,374	352,490	2,800,635	629,734
SEA BASS.	69,098	23,498	66,869	23,808
SEA ROBIN	65,220	2,975	56,025	2,637
SEA TROUT (WEAKFISH).	116,349	19,736	63,370	10,225
SHAD.	13,680	1,893	12,636	2,062
SHARKS:				
GRAYFISH (DOGFISH).	144,420	12,643	136,214	9,574
UNCLASSIFIED. . . .	1,117	83	5,300	380
SKATES (RAJAFISH) . .	8,211	431	10,237	511
SPEARING (SILVERSIDES)	67,120	11,945	123,350	20,360
STRIPED BASS.	1,457,775	356,624	1,489,775	338,074
STURGEON.	11,483	1,623	10,896	1,784
SWELLFISH (BLOWFISH).	260,571	13,999	224,418	16,887
SWORDFISH	2,460	910	56,448	26,828
TAUTOG (BLACKFISH). .	41,825	1,943	87,145	3,486
TILEFISH.	9,600	1,263	6,192	958
TUNA: BLUEFIN. . . .	11,911	1,187	27,892	4,116
LITTLE (ALBACORE). .	14,669	881	11,794	819
WHITE BAIT.	5,400	810	-	-
WHITING	2,091,689	134,221	3,311,464	199,784
WHITE PERCH	64,618	13,165	86,100	17,899
UNCLASSIFIED:				
FOR FOOD.	227,538	22,755	259,219	25,920
FOR BAIT, REDUCTION, AND ANIMAL FOOD. .	-	-	6,184,960	54,118
TOTAL FISH . . .	26,451,963	2,287,829	44,895,203	2,934,017
SHELLFISH				
LOBSTERS, NORTHERN. .	1,416,225	1,456,141	1,166,876	1,181,679
CLAM MEATS: HARD . .	7,516,260	8,178,905	6,986,028	7,268,040
SOFT . .	190,672	76,176	201,552	81,879
SURF . .	3,431,416	389,614	3,007,895	295,249
CONCH MEATS	38,025	7,191	48,405	10,399
MUSSEL MEATS, SEA . .	209,850	63,012	206,690	63,348
OYSTER MEATS.	212,956	473,057	175,405	377,717
SCALLOP MEATS, EDIBLE:				
BAY	248,635	376,541	201,484	350,174
SEA	596,946	642,244	1,480,253	1,665,432
SQUID	529,586	54,883	973,273	68,426
TOTAL SHELLFISH.	14,390,571	11,717,764	14,447,861	11,362,343
GRAND TOTAL. . .	40,842,534	14,005,593	59,343,064	14,296,360

New York Landings for Specified Period, 1969 and 1968

Anon, New York Landings, Dec. 1969

III

SEWAGE SLUDGE AND DREDGE SPOIL

A. Introduction

The Ad Hoc Committee for the Evaluation of the Influence of Dumping in the New York Bight (Ad hoc Committee, 1970) lists five major sources of pollution of the New York Bight:

(1) Vessel discharge of trash, bilge wastes, and sewage.
(2) Ocean disposal of sewage sludge, construction materials, industrial wastes, and dredge materials.
(3) Sewer outfalls.
(4) River discharge and land runoff.
(5) Accidental spills on land and at sea.

Its report emphasizes that ocean disposal is NOT, relatively speaking, one of the more serious sources of pollution. Nevertheless, it is a large contribution and its relative size will probably continue to increase. Requirements by state and federal regulating agencies that all waste waters be given secondary treatment to the extent of a minimum BOD removal of 80%, while reducing the pollution entering the Bight from the Hudson and adjacent waterways, can be expected, even quite apart from the growing population of the metropolitan area, to enormously increase the quantities of sludge that must be disposed. (Chasick, 1969).

The treatment procedures resulting in sludge formation are diagramed in Figures 23-25.

The outlook in the case of dredge spoil may not be so grim. A decline in shipping activities would tend to alleviate some of the port's pollution problems, although this may tend to be offset by the growth in pleasure craft which are more difficult to police and probably more careless in their operation. The most troublesome constituent of the material dredged from the bottom of the port appears to be the petrochemicals. Present widespread concern with oil pollution of the seas will unquestionably lead to more strict control of the handling and shipping of petroleum and of vessel discharge, and such control should contribute greatly to reducing the hazard of the spoil. Similarly, recent alarm over heavy metal contamination of fish and other marine foodstuffs again almost certainly will result in stricter control measures which will at least reduce the input of the toxic substances into the harbor sediments.

B. Quantities Involved

The quantities of solid wastes being disposed in the coastal waters of the United States are enormous and increasing rapidly. In 1968, about 48,000,000 tons of waste were dumped into the sea even although most wastes were incinerated or disposed on land (Train, Cahn, and MacDonald, 1970). Of this material Table 3 shows that the majority (80%) is dredge spoil. Table 4 shows that much of this spoil is contaminated. Spoil is of particular concern to the Corps of Engineers since much of the dredging is done either by the Corps or by private contractors working under Corps permit.

The dumps in the Bight bear the nation's largest load. Between 1944 and 1968, 9,600,000 tons/yr of solid wastes were dumped into the waters of the New York Bight (see Table 5). In fiscal year 1968 the dumped materials amounted to over 17,000,000 yds^3 (Table 6). Table 7 shows the quantities of ash disposed of in the Bight over the years 1960 - 1968.

Gross (Gross, 1970b) has made some interesting comparisons which can help to give us a clearer idea of the gigantic magnitude of these quantities. He points out that 9,600,000 tons/yr of solid wastes corresponds to 1 ton/person/yr or 6 lbs/person/day and that, except for the Gulf of Mexico, the wastes from the New York metropolitan area are the largest source of

TABLE 3

Ocean Dumping: Types and Amounts, 1968

(In tons)

	Atlantic	Gulf	Pacific	Total	
Dredge Spoils	15,808,000	15,300,000	7,320,000	38,428,000	80
Industrial Wastes	3,013,200	696,000	981,300	4,690,500	10
Sewage Sludge	4,477,000	0	0	4,477,000	9
Construction and Demolition Debris	574,000	0	0	574,000	<1
Solid Waste	0	0	26,000	26,000	<1
Explosives	15,200	0	0	15,200	<1
Total	23,887,400	15,966,000	8,327,300	48,210,700	100

(From Train, Cahn, and MacDonald, 1970)

TABLE 4

Estimated Polluted Dredge Spoils

Coastal Area	Total Spoils (in tons)	Estimated % of total polluted spoils*	Total polluted spoils (in tons)
Atlantic Coast	15,808,000	45	7,120,000
Gulf Coast	15,300,000	31	4,740,000
Pacific Coast	7,320,000	19	1,390,000
Total	38,428,000	34	13,250,000

* Estimates of polluted dredge spoils consider chlorine demand; BOD; COD; volatile solids; oil and grease; concentrations of phosphorus nitrogen, and iron; silica content; and color and odor of the spoils.

(From Train, Cahn, and MacDonald, 1970)

TABLE 5

Average Amount of Waste Solids from New York Metropolitan Region Dumped in Western Long Island Sound and on Continental Shelf (New York Bight)

	Millions of Tons Per Year	
	1960-1963	1964-1968
Western Long Island Sound	0.74[1]	1.9[1]
New York Bight		
Mud disposal area		
Private contractors	2.2[1]	3.4[1]
Federal dredges	4.2[2]	3.4[2]
Cellar dirt disposal area	0.67[1]	0.59[1]
Sewage sludge disposal area	0.11[3]	0.15[3]
Waste chemical disposal area	0.10[5]	0.18[5]
Total	8.02	9.62

[1]Estimated bulk density 1.1 g/cm^3.

[2]Estimated bulk density 1.3 g/cm^3.

[3]Discharged as liquids containing 4.5% solids by weight, assumed density of solids 1 g/cm^3.

[4]Discharged as liquid, estimated solid content 5% by weight.

(Gross, 1970b)

TABLE 6

During Fiscal Year 1968 disposal of materials in the dumping grounds amounted to 17,110,144 cubic yards as follows:

Ground	Cubic Yards
Mud Dumping	8,784,200
Cellar Dirt	318,875
Sewage Sludge	4,833,730
Waste Acid	3,117,623
Wreck	3,000
Chemical (Toxic)	52,716
Total	17,110,144

(Ad Hoc Comm., 1970)

TABLE 8

Sediment Discharge of some U.S. Atlantic Coast Rivers

North Atlantic Region	Annual Discharge of Suspended Sediment (10^6 tons per year)	(tons per year/km^2 of drainage basin)
NORTH ATLANTIC REGION	6.1	15
Connecticut River	0.089	3.1
Hudson River	0.40	12
Raritan River	0.071	29
Delaware River	0.72	21
Susquehanna River	0.96	14
Potomac River	1.4	37
James River	1.0	36
SOUTH ATLANTIC REGION	21.8	68
Roanoke River	2.5	99
Peedee River	1.6	59
Santee River	3.4	90
Savannah River	2.6	90
Ogeechec River	1.2	87
Altamaha River	3.0	83

From Gross, (1969) (after Dole & Stabler, 1909)

TABLE 9

Suspended Solids Discharged by some Major Rivers

	(10^6 tons/yr)	(tons per yr/km^2 of drainage basin)
Niger River	5	4.6
Amazon River	400	65
Congo River	71	18
Mississippi River	344	107
Colorado River	149	418
Rio Grande River	9.4	136
Rhine River	0.5	3
Yellow (Hwang Ho) River	2083	2910
Ganges River	1600	1540
Bramaputra River	800	1430
Mekong River	187	479

From Gross, (1969) (after Holeman, 1968) sediment discharging directly into the North Atlantic Ocean from the North American continent. For purposes of comparison Tables 8 and 9 tabulate some yearly sediment discharge of selected U.S. Atlantic Coast and major world rivers.

TABLE 7

Ash from New York Metropolitan Region dumped in offshore waste disposal sites.

Fiscal Year	Volume (10^3 cubic meters per year)	Tonnage[1] (10^3 tons per year)
1960	76	53
1961	91	64
1962	230	160
1963	250	180
1964	120	84
1965	66	46
1966	140	98
1967	170	120
1968	150	100
Average 1960-1963	161	114
1964-1968	130	90

[1]Bulk density 0.7 g/cm^3.

(Gross, 1970c)

The "normal" sediment load of the Hudson River was estimated to be 400,000 tons/yr around 1900 (Dole and Stabler, 1909) but in 1960 it was estimated to be more than double this value at 830,000 tons/yr (Panuzio, 1965). Between 1964 and 1968 about 700,000 tons/yr of wastes were dumped into the river which may have reached the harbor where they were subsequently dredged up and barged to the waters of the Bight (Gross, 1970b).

The waste materials exceed river sediment discharge per unit area in the New York Bight by some 3 to 30 tons/km^2/yr, (Gross, 1970b).

In another provokative comparison, Gross (1970b) points out that if the solid wastes dumped in the waters of the Bight were deposited instead uniformly over Manhatten Island they would accumulate at a rate of 14 cm (5.5 in)/yr.

If these statistics are not grim enough in themselves, we must remember as we have mentioned before, that these wastes were dumped into waters already grossly polluted (Table 10).

Over 1,000,000,000 gal/day of sewage is discharged directly into the waters entering the New York Bight from both New York and New Jersey. Only about half this is subjected to secondary sewage treatment and the treatment plants are so overloaded that the treatment is not fully effective. All the entrances leading to the Bight are polluted. The Hudson River is already burdened with 10 times more pollution than it can accomodate by natural biological decomposition (Ketchum, 1970). By natural processes the Hudson River can recover from the sewage contamination of 1,200,000 people but in the metropolitan area the sewage effluents of a population 10 times greater are being discharged into a river already polluted by municipalities upstream.

Presently, there is some degree of secondary treatment for about 75% of the 1300 mgd of sewage treated, but about 325 mgd of raw sewage continue to be discharged into the Hudson, mainly from the Northwest side of Manhatten (Eisenbud, 1970).

TABLE 10

Sewage Discharge

Receiving Water	Number of Discharges	Total Flow (MGD)
New York - New Jersey[1] Metropolitan Area	57	1682.0
Intracoastal Waters[2] of Nassau County	8	76.0
Atlantic Ocean (New Jersey)	31	39.0
Intracoastal Waters[3] of New Jersey Coastal Area	34	46.0
TOTAL	130	1843.0

1 Includes the municipal wastewater discharges from New York and New Jersey to: the Hudson River from the New Jersey-New York State line; the Upper and Lower Bays of New York Harbor; the Raritan Bay; the Arthur Kill; the Kill Van Kull; the East River and Jamaica Bay.

2 Includes the municipal wastewater discharges from Nassau County, New York to the intracoastal waters along the southern Long Island shore.

3 Includes the municipal wastewater discharges from Monmouth, Ocean, Atlantic and Cape May Counties to the intracoastal waters along the New Jersey eastern shore.

(Ad Hoc Comm., 1970)

350,000,000 gal/day of raw sewage are poured into the Hudson and East Rivers which eventually find its way to the Bight (Peter, 1970).

The future outlook is most bleak. The population of the coast region is expected to increase from 68,000,000 in 1970 to 72,000,000 in 1980, to 93,000,000 in 1990 to 107,000,000 in 2000 (Train, Cahn and MacDonald, 1970). The quantities of wastes dumped in the ocean has been climbing (Table 11). Gross (1970b) notes that the solid wastes from New York City dumped into coastal waters increased from 8,000,000 tons in 1960-1963 to 9,600,000 tons in 1964-1968, an increase of about 4%/yr. The sludge barged to sea increased from 99,000 tons in 1960 to 220,000 tons in 1980, a 120% increase in 20 years (Train, Cahn, and MacDonald, 1970).

Based on conservative estimate of 8 lbs solid waste/person/day, the generation rate in 1980 will be over 150,000,000 tons/yr. If 10 lbs/person/day are generated total wastes in the coastal area will be nearly 200,000,000 tons/yr or more than 3X the present level. "The pressure to use the ocean for waste disposal will increase...." (Train, Cahn and MacDonald, 1970).

These projections are particularly disturbing for, as we shall see, the pollution tolerating capacity of the present Bight dumping areas appears to have been exceeded a few years ago.

C. <u>Physical-Chemical Properties of the Wastes</u>

Sewage sludge is a semi-liquid waste. The % solids of sewage after primary sedimentation is 2.5-5 and after the secondary treatment trickling process or activated sludge process, 0.5-5 and 0.5-1% respectively (Amer. Chem. Soc., 1969). New York activated sludge is thickened in circular gravity thickeners to yield a relatively thick sludge of approximately 5 to 6% total solids; this represents 0.0025 fraction of the original volume (Chasick, 1969).

TABLE 11

Ocean Dumping: Historical Trends, 1949-1968[1] (66)

Coastal Area	1949-1953		1954-1958		1959-1963		1964-1968	
	Total	Avg./Yr.	Total	Avg./Yr.	Total	Avg./Yr.	Total	Avg./Yr.
Atlantic Coast	8,000,000	1,600,000	[2]16,000,000	3,200,000	27,270,000	5,454,000	31,100,000	6,200,000
Gulf Coast	[3]40,000	8,000	283,000	56,000	860,000	172,000	2,600,000	520,000
Pacific Coast	487,000	97,000	850,000	170,000	940,000	188,000	3,410,000	682,000
Total	8,527,000	1,705,000	17,133,000	3,426,000	29,070,000	5,814,000	37,110,000	7,422,000

1 Figures do not include dredge spoils, radioactive wastes, and military explosives.

2 Estimated by fitting a linear trend line between data for preceding period and data for succeeding period.

3 Disposal operations in the Gulf of Mexico began in 1952.

(Train, Cahn and MacDonald, 1970)

Many nutrient materials are soluble, thus compared to the original sewage the nutrient content of the sludge is small (Table 12) therefore sludge has little nutrient value on the waters in which it is dumped.

In terms of pollution, the most troublesome components of sewage sludge are the organic content and apparently the toxic heavy metal content. Sewer sludge from plants in New York City and New Jersey are rich in organic matter (Table 13), the total loss on ignition ranging from about 46 to about 80% of the dry weight of the material and the oxidizable carbon content of the samples ranged from 18 to 26 % (Gross, 1970). The remaining non-organic fraction of the sludge is largely composed of aluminosilicate materials chemically similar to shale (Gross, 1970). As for the nature of the organic material, sewage itself contains both volatile and non-volatile acids. Among the soluble, non-volatile acids found are gluturic, glycolic, lactic, citric, benzoic and phenyl lactic. Among the soluble sugars found are glucose, sucrose, and lactose (Walter, 1961). Walter (1961) gives the % total carbon composition of the suspended solid material in sewage as shown in Table 14.

Major and minor elements present in sludge are summarized in Tables 15 and 16. Especially noteworthy are the large concentrations of some of the heavy metals. Sewer sludge contains relatively high concentrations of Pb, Cr, Cu, and other heavy metals (Gross, 1970). Compared to sedimentary rocks and soils sludge contains 150 times more Au, 10 times more Cr, 50 times more Cu, 50 times more lead, 30 times more Sn, and 30 times more Zn (Gross, 1970). These are all common industrial heavy metals.

Table 17 compares the concentration of some heavy metals found in sludge and spoil to their "natural" level in sea water and to their concentrations toxic to marine life.

TABLE 12

Summary of Nutrients in the Alki Point Plant (Seattle, Wash.) Effluent and Digested Sludge (Sylvester, 1962)

Source	Min.	Max.	Mean	Lb/Day
Effluent (mg/1):				
Soluble PO_4	0.17	6.72	1.75	124
Total PO_4	2.3	10.5	5.4	382
Ammonia N	1.1	11.3	6.1	432
Nitrate N	0.22	5.8	1.9	134
Kjeldahl N	0.55	4.8	2.1	148
Digested sludge (mg/g dry solids):				
Total PO_4	1.8	11.2	5.1	9
Nitrate N	0.3	12	4.9	9
Kjeldahm N	2.8	6.1	4.3	8
Seawater* mg/1):				
Soluble PO_4	0.076	0.315	0.226	---

TABLE 13

Some Chemical Properties of Sewage Sludges,
New York Metropolitan Region

Sample Number	CARBON Total (%)	Carbonate (%)	Oxidizable Carbon (%)	Oxidizable Carbon (MEQ/g)	Reducing Capacity (MEQ/g)	Sulfide (MEQ/g)
690818001	34.4	0.5	21.8	72.7	131.2	0.1
690818002	31.8	0	23.5	78.3	118.2	0.3
690818003	30.8	1.5	20.9	69.7	114.1	0.4
690818004	28.5	0	18.3	61.0	110.2	0.2
690918005	28.4	0.3	20.9	69.7	110.1	0.2
690819001	25.4	0.3	18.1	60.3	123.8	0.3
690819003	29.6	0.2	21.1	70.3	127.9	0.3
690819004	27.8	0.1	20.3	67.7	106.3	0.3
690819005	36.4	2.0	18.8	62.7	120.4	0.2
690904001	31.7	0	21.5	71.6	117.2	0.2
690904002	40.9	0	22.9	76.3	139.4	0.2
690904003	28.9	0	17.9	59.7	118.7	0.2
690910001	29.9	0	17.9	59.7	110.1	0.2
690925001	39.7	0	27.7	92.3	162.4	0.2
690925003	41.9	0	23.1	77.0	153.2	0.2
690925005	17.7	0	13.2	44.0	95.8	0.1
690925007	47.2	0	25.7	85.7	181.2	0.1
Average	32.4	0.3	20.8	69.3	125.9	0.2

(Gross, 1970)

TABLE 14

% Total Carbon Composition of the Suspended Solid Material in Sewage

Unidentified	63%
Protein	20
Carbohydrates	10
Amino Sugars	3
Soluble Acids	1
Fats - Ester	1
Fats - Acid	1
Muramic Acid	0.4
Anionic Detergents	0.4
Amide	0.2

(Walter, 1961)

TABLE 15

Abundance of Major Elements in Typical Sewage Sludge and Natural Sediment Deposits

SEWAGE SLUDGES					SEDIMENTARY ROCKS	
As Element	As Oxides			Carbon-free Sludge [a]	Shale	Sandstone
Si	10%	SiO_2	21.4%	63.6%	58.1%	78.3%
Ti	0.25	TiO_2	0.4	1.2	0.65	0.25
Al	2.5	Al_2O_3	4.8	14.3	15.4	4.8
Fe	1.3	FeO	1.7	5.0	6.1	1.3
Mg	0.6	MgO	1.0	3.0	2.4	1.2
Ca	1.5	CaO	2.1	6.2	3.1	5.5
Na	0.75	Na_2O	1.0	3.0	1.3	0.45
K	1.0	K_2O	1.2	3.6	3.2	1.3
C	31	Organic	56		0.80	
P	0.55	P_2O_5	1.2		0.17	0.08
		CO_2			2.6	5.0

a Chemical composition recalculated, and adjusted to 100% after subtracting carbon and phosphorus content.

(Gross, 1970)

TABLE 16

Spectrochemical Analyses of Sewage Sludges, New York Metropolitan Region (Gross, 1970)

Table 16. Spectrochemical analyses of sewage sludges, New York Metropolitan Region. (Gross, 1970)

	New York City				
	Wards Island	Hunts Point	Newtown Creek	Bowery Bay	Tallmans Island
Silicon-	7.0%	8.9%	11.%	10.%	10.%
Iron-	1.0	2.6	1.2	3.2	1.5
Aluminum-	1.7	2.5	2.5	2.7	2.7
Calcium-	1.2	1.8	3.7	1.6	1.4
Magnesium-	0.63	0.69	0.59	0.84	0.80
Copper-	0.056	0.14	0.16	0.19	0.11
Sodium-	2.0	1.2	1.3	1.7	1.1
Titanium-	0.17	0.38	0.23	0.56	0.27
Chromium-	0.050	0.11	0.080	0.25	0.085
Potassium-	2.5	2.7	1.7	2.7	1.8
Phosphorus-	0.29	0.91	0.65	0.77	0.70
Barium-	0.040	0.059	0.10	0.071	0.042
Boron-	0.0016	0.0024	0.0034	0.0020	0.0034
Lead-	trace< 0.005	0.055	0.12	0.12	0.056
Manganese-	0.014	0.017	0.021	0.029	0.040
Nickel-	0.0069	0.019	0.025	0.090	0.033
Molybdenum-	0.0011	0.0016	0.0033	0.0039	trace 0.002
Tin-	0.021	0.034	0.028	0.048	0.022
Vanadium-	0.0076	0.015	0.0059	0.011	0.0080
Bismuth-	ND< 0.002.....	.....	trace< 0.002	ND< 0.002.....	.....
Silver-	0.0015	0.0014	0.0016	0.0033	0.0021
Zinc-	0.069	0.25	0.24	0.29	0.17
Zirconium-	0.0053	0.012	0.027	0.021	0.012
Cobalt-	0.0015	0.0036	0.0039	0.0061	0.0031
Strontium-	0.0096	0.015	0.0097	0.015	0.0075
Arsenic-	ND< 0.06.....	.....	.....	.....	.....
Mercury-	ND< 0.09.....	.....	.....	.....	.....
Antimony-	ND< 0.008.....	.....	.....	.....	.....
Thorium-	ND< 0.10.....	.....	.....	.....	.....
Beryllium-	ND< 0.0003.....	.....	.....	.....	.....
Gallium-	ND< 0.003.....	.....	.....	.....	.....
Yttrium-	ND< 0.009.....	.....	.....	.....	.....
Ytterbium-	ND< 0.004.....	.....	.....	.....	.....
Cerium-	ND< 0.04.....	.....	.....	.....	.....
Other elements-	nil	nil	nil	nil	nil
Loss on ignition (sulfate ash)	64.55%	53.75%	49.10%	47.90%	55.40% .....

ND Not Detected

—— Maximum value for element

..... Minimum value for element

TABLE 17

Heavy Metals Concentrations in Sewage Sludge (in parts per million)

Metal	Concentrations in Sewage Sludge			Natural Concentrations in sea water	Concentrations toxic to marine life
	Min.	Avg.	Max.		
Copper	315	643	1,980	.003	.1
Zinc	1,350	2,459	3,700	.01	10.0
Manganese	30	262	790	.002	---

Heavy Metals Concentrations in Dredge Spoils (in parts per million)

Metal	Concentrations in dredge spoils	Natural Concentrations in sea water	Concentrations toxic to marine life
Cadmium	130	.08	.01-10.0
Chromium	150	.00005	1.0
Lead	310	.00003	.1
Nickel	610	.0054	.1

(Train, Cahn, and MacDonald, 1970)

Sewer sludge is also believed to contain some petroleum materials, although far less than dredge spoil. The radio-isotope content of sewage and sewage sludge have also been identified (Folsom and Mohanrao, 1961). The raw sludge of the Hyperion Plant (Los Angeles) contained 0.81 to 124.8 μμc/g Cs^{137} and 0.1 to 2.9 μμc/g Co^{60} while the sludge being piped into the Pacific has a Cs^{137} content of 0.35 to 7.78 μμc/g. The presence of I^{131}, Zn^{65}, K^{40}, Ra^{226} and Th^{232} were also noted in Hyperion Plant sewage. With respect to Zn^{65} the raw sludge from a Portland, Oregon plant had 0.6 μμc/g while the digested sludge had 0.9 μμc/g.

In the case of the dredge spoil, the recent studies seem to be pointing in the direction that, from a pollution standpoint, the most dangerous constituents of this material are petrochemicals and again, heavy metals.

The ocean floor in the sludge dumping area is also scattered with refuse and human artifacts, in some areas these are more than $30/0.1m^2$ such objects (Pearce, 1969). The physical appearance of the bottom is evidently exactly that of what the Bight has become - a dump. The probable density of dredge material is 1.3 tons/m^3 which agrees with sediment bulk densities (Panuzio, 1965) while building rubble has a bulk density of 1.1 tons/m^3 (Gross, 1970b). The uncertainty in the bulk density of waste solids is at least ±0.2g/cm^3 which gives rise to an uncertainty of at least 15% in estimating total quantities of solid waste disposed (Gross, 1970b). Hudson River dredge wastes are primarily silt with particle sizes ranging from 8 to 66μ. The wastes dredged from the harbor bottom are largely silicate but contain on the average 8-10% organic matter(Panuzio, 1965) in contrast to the 5.5% organic matter in Hudson River sediments (McCrone, 1967). In the spoil dump the particle size of the sediments are more irregular and there are less human artifacts than in the

TABLE 18

Estimated amounts of oxidizable carbon and potentially troublesome elements discharged with various waste solids in offshore disposal sites, New York Metropolitan Region. Discharges expressed in grams per year (10^6 grams equals one metric ton).

Type of waste solid	Annual Discharge of Solids	Annual Discharge of Oxidizable Carbon	Annual Discharge of Minor Elements				
			Ag	Cr	Cu	Sn	Pb
Dredged Wastes*	35×10^{11}	6×10^{10}	5×10^{7}	1.4×10^{9}	7×10^{8}	2×10^{8}	2×10^{9}
Sewage Sludge**	2×10^{11}	4×10^{10}	2×10^{6}	2×10^{8}	2×10^{8}	6×10^{7}	10^{8}
Fly Ash	10^{11}	3×10^{9}	$<10^{5}$	2×10^{7}	10^{7}	$<2 \times 10^{6}$	3×10^{7}

* Oxidizable carbon discharges calculated from observed oxidizable carbon concentrations in harbor sediment, corrected for carbon losses during dredging operations.

** Oxidizable carbon 20% by weight (Gross 1970a)

(Gross, 1970c)

sludge disposal area (Pearce, 1969). Tables 18-22 summarize further physical and chemical properties of dredge spoil, sewage sludge and some other solid wastes being dumped in the Bight.

Although in terms of the quantities involved dredge spoil makes by far the greatest contribution to the solid wastes disposed in the Bight, it should be noted that it is composed for the most part of inert mineral substances and would not constitute a pollution problem in itself were it not contaminated with petrochemicals, heavy metals, and pesticides.

TABLE 19

Some Physical Characteristics of Barged Wastes, New York Metropolitan Region.

Samples	Bulk Density (g/cm^3)	Grain Density (g/cm^3)	Median Particle Size (microns)
Coal Ash,			
Plant 1	0.71	2.24	18
Plant 2	0.72	2.12	25
Dredged Sediment			
Lower Hudson River	-----	2.63	12
Upper New York Bay	-----	2.45	25

(Gross, 1970c)

TABLE 20

Physical Properties of Some Waste Solids from the New York Metropolitan Region

Material	Typical Bulk Density (range) (tons/cubic meter)	Median (range) Grain Size (microns)	Reference
Stone and Brick	1.1 (0.9-1.3)	--	1
Incinerator Ash	0.40	2400	1
Dredged Sediments:			
Hudson River Silt	0.65	45 (30-65)	2
Raritan River Silt	0.65	9 (8.28)	2
Ambrose Channel Sand	1.6	160 (160-240)	2
Southern Long Island Beaches	1.6	400 (200-530)	2

[1] From Gross (1969) after Kenahan, C.B., P.M. Sullivan, J.A. Ruppert and E.F. Spano. 1968, Composition and Characteristics of Municipal Incinerator Residues. U.S. Bureau of Mines, Report of Investigation 7204.

[2] From Gross (1969) after U.S. Army Corps of Engineers, New York District Operations Office. Unpublished data.

TABLE 21

Physical Properties of Sediment Dredges In New York Metropolitan Area

Dredged Area (Years of Observation)	Median Grain Size (microns)	Grain Density** (g/cm^3)	Sediment Density-In Place (g/cm^3)	Porosity %
Hudson River		2.63		
(1955-1968)	44	2.64	1.24	85
	65	2.69	1.24	
	28	2.66	1.43	73
Lower Bay*	55	2.55	1.34	78
(1954-1967)	110	2.69	1.40	75
	46		1.3	79
New York-New Jersey Channels	350	2.79	1.43	
(1958-1967)	41	2.69	1.31	80
Raritan River (1958-1967)	9	2.62	1.42	75
Ambrose Channel	160	2.625	2.09	32
(1956-1968)	220	2.636	1.82	50
Sandy Hook Channel	250	1.89	1.89	47
(1960-1968)	220	1.98		42
South Shore Long Island	530	2.67	2.07	38
	410		1.92	40
(1955-1968)	270		1.98	42

* Loss on Ignition: 15.4%
13.0%
2.3%

** One gram per cubic centimeter is equivalent to one metric ton per cubic meter or 62.4 pounds per cubic foot.

TABLE 22

Some chemical and physical properties of waste solids, New York Metropolitan Region (data given for samples dried at room temp.)

Sample	Total Carbon (%)	Oxidizable Carbon (%)	Carbonate Carbon(%)	Reducing Capacity (MEQ/g)	Bulk density(g/cm^3)	Grain density(g/cm^3)
Ash from coal combustion						
Plant 1	8.4	4.8	0	15.4	0.71	2.24
Plant 2	3.3	2.4	0	8.3	0.72	2.12
Permentation wastes (solids)	21.9	16.7	2.5	114	1.05	----
Dredged Sediment						
Lower Hudson River	2.40	1.67	0.07	7.67	----	2.63
Upper New York Bay	2.88	1.70	0	6.86	----	2.45
Sewage Sludges[1]						
Average	32.4	20.8	0.3	126	1.013	----

[1] Data from Gross, 1970

(Gross, 1970c)

IV

THE EFFECTS OF WASTE DISPOSAL

A. Waste Transport and Dispersal and Physical Effects

There has been a small amount of research done on barge dumping. Ketchum and Ford (1948) published a paper on dispersion of acid-iron wastes in the wake of a barge. Beyer (1955) did a study of sewage sludge dumping in the Oslo fjord. Saila studied dredging spoil dumping in the Newport Bight (1968), and Crouir (1967) has done the same in Chesapeake Bay. Buelow (1968) has also studied the dumping of sewage sludge in waters off New York Harbor and Redfield and Walford (1951) have examined the disposal of waste chemicals.

The sum of these studies gives only an approximate picture of the settling and dispersion patterns and rates. There areinsufficient data available to quantify this picture. The largest portion of the dumped material sinks fairly rapidly, within a few minutes of the dump, to the bottom. Beyer (1955) noted, however, that a large cloud of very fine particles remained at or near the surface for periods of up to four hours. This cloud could be carried three or four kilometers under the influence of wind and current. Saila (1967) traced the settling pattern of dredging spoils by using turbidity measurements. He estimates that up to twenty-five percent of the dumped material remains suspended in the water column. He found that two slicks tended to form within an hour of the dumping. One at the surface and one at roughly mid-depth, which probably was due to the density gradient at the thermocline. He theorizes that these slicks are composed of oils and organic matter with positive buoyancy, which coagulate at the bottom and then rise. He found that these slicks break up after four to five hours, which agrees with most estimates from outfall studies, both theoretical and applied.

The general pattern of what will happen to sewage sludge or dredging spoils dumped in the Bight can be predicted on the basis of the above studies.

Over seventy-five percent of the material can be expected to settle rapidly within the dumping area. The remaining portion will travel with the current for a period of several hours while slowly settling. This direction is generally onshore in the summer and offshore in the winter. The Sandy Hook Laboratory reports large quantities of suspended material near the dumping area. A very small portion (Saila (1968) estimates 1-5%) will be bouyant and will disperse either at the surface or along a density gradient. The theoretical works predict that this dispersion will be largely lateral, with only a small vertical component. The mixing rate, particularly vertical mixing will be greatly increased with increased wave action, such as occurs in storms (Rice and Johnson, 1954). Ketchum (et al. 1951) found that storms in the New York Bight produce vertical homogeneity, which confirms the prediction of Rice and Johnson (1954). And, indeed, Pearce's (1969) findings do appear to indicate that storms are capable, not only of mixing the water column vertically, but of actually moving the contaminated sediments around. As a consequence cores taken in the area will show alternating clean and polluted layers.

Screening can be used to remove floatable material (Theroux et al., 1961). In addition to the surface slicks and debris patches which are frequently observed to the east of the dump areas (Pearce, 1969) and which presumably result from the actual dumping operation, the material which does settle to the bottom can periodically gasify and then float contamination to the surface (Sylvester, 1962).

In the waters of the New York Bight the bottom sediments in the disposal area are characterized by an organic content greatly in excess of the normal value (less than 5%), and currents spread this high organic content zone northeast towards the coast of Long Island (Figure 26). East of the disposal area is a region of abnormally high organic content (between 5 and 10%) (Figure 26) of rather mysterious origin. It is not associated with the dumping area and may be the result of normal natural processes, (Ketchum, 1970a). The heavy metal content of the sediments leads to the same conclusion, namely the sludge contaminated area is spreading in a general water movement to the northeast and east (Pearce, 1969). In contrast to the sludge, the dredge spoil tends to remain where it was dumped (Pearce, 1969; Rev. Committee, 1970).

Still another factor in the spread of the contaminated areas is the failure to dump in the designated areas. Despite patrolling,surveillance of the dump areas is not adequate and "short dumping" is known to occur. Also there is a lack of bouys and other navigational guides at the dumping site (King, 1970).

More information on the depth of contamination of the bottom sediments in and near the dump area is needed. One core indicated that the contamination penetrates to a depth of three feet (Pearce, 1969). Ketchum as quoted by the Review Committee has estimated that, despite spreading and decomposition much of the sludge dumped over the past forty years may still be accumulated on the bottom. If such is the case, in the words of the Committee "this would indicate that the rate of decomposition in the marine environment is very slow and raises a danger signal that we may have already exceeded safe limits of disposal."

B. Chemical Effects

Dredge spoil has been exposed to a brackish or marine environment for extended periods prior to dredging and dumping, similarly sewage sludge has been formed in an aqueous medium, consequently we expect little non-biological chemistry to occur immediately upon the dumping of these materials in the sea although these may be some aggregation and subsequent precipitation of colloidal material due to the high ionic strength of sea water.

As noted above the most damaging pollutants of the dredge spoil are petrochemicals and heavy metals and of the sewer sludge, carbonaceous material and heavy metals. Samples taken from the dredge spoil area contained hexane extractable material alone in the lethal range (0.5 to 5.0%) for oil pollution on marine plants and animals (Pearce, 1969). Petroleum contamination in New York Harbor is very extensive. The petroleum coats solid particulate material and is carried to the bottom. The water-oil emmulsion formed results in sediments with the consistency of mayonnaise (Pearce, 1969). Petrochemicals selectively solvent extract both heavy metals and pesticides (Hartung, 1969; Pearce, 1969, Peter, 1970). This material is then dredged up and it together with its toxic burden of heavy metals and pesticides is dumped in the waters of the Bight. The sediments in the spoil dump have even higher heavy metals than those in the dredge dump and they _always_ have a noticeable odor of petrochemicals (Pearce, 1969). The pesticide content of the contaminated sediments runs between 0.013-0.019 ppm DDE, 0.039-0.81 ppm DDD, and 0.013-0.126 ppm DDT (Pearce, 1969).

Fortunately, as a consequence of interest excited by catastrophic and highly publicized oil spills and leaks, we are now beginning to get some detailed information on the chemical fate of hydrocarbons in the marine environment and on their ecological effects.

The visually obvious effects of an oil spill at sea soon disappear and the opinion has been expressed that polluting crude and fuel oil do not persist for long periods in the marine environment (Davies and Hugues, 1968). After some initial degradation near the surface by the action of sunlight aliphatic, olefinic, and naphthenic components of the sinking oil contamination are subjected to microbial attack by a number of widely distributed organisms such as _Coryrebacterium_, _Nocardia_, _Streptomyces_, _Penicillium_, _Candida_, _Mycobacterium_, _Micrococcus_, and _Pseudomonas_ (Amphlett, 1968; Quayle, 1967; Zobell, 1946).

It is very important to notice, however that biodegradation of petroleum material requires molecular oxygen or oxygenated anions such as sulfate and it is very doubtful that most of such processes can occur in oxygen-depleted waters such as encountered in the contaminated waters of the New York Bight, and even if some available oxygen does remain in the waters it will soon be depleted in the bottom material. The existence of vast natural deposits of hydrocarbons is eloquent testimony to the persistence of these materials under anoxic conditions.

An oil spill near the Woods Hole Oceanographic Institution in 1969 enabled scientists there to make one of the most detailed studies to date of the chemical history and ecological impact of hydrocarbon contamination of the marine environment (Hunt and Blumer, 1970). Although this spill differed from the New York Bight situation in at least two important respects:

1) the spill occurred in shallow waters well-mixed by meteorological conditions

2) the spill consisted of a very light fraction (No. 2 diesel fuel oil) with a relatively high concentration of aromatic compounds, whereas the spoil probably contains heavy tars and residues

some of the findings are relevant to the chemical and biological effects of the dredging spoil. Superficially the oil contamination soon disappeared from the initially contaminated area after a massive kill of the local biota. Detailed chemical analyses however, in contrast to the findings cited above, revealed that not only did contamination persist in the bottom sediments and the surrounding organisms for very long periods of time, (Blumer, Couza and Sass, 1970) but that the most persistent contaminants were also the most dangerous - highly toxic aromatic compounds some of them known carcinogens. It was also discovered that the hydrocarbons continued to spread in the bottom sediments until an area was covered much greater than that of the original contamination. This spreading can be due to hydraulic pressure from shore originating fresh waters and/or from diffusional processes. The latter but probably not the former mechanism should also be operating in the bottom material of the New York Bight.

Natural water systems are capable of cleansing themselves of enormous influxes of hydrocarbons. Although the site of very dirty drilling operations for more than twenty years, surface sediment cores from the bottom of Lake Maracaibo, Venezuela, are clean of hydrocarbons (Hunt, 1970), probably because its waters are rich in petroleum-eating organisms. However, if the supply of oxygen is depleted, as now appears to be the case in the case in the waters of the New York Bight, their hydrocarbon - removal capacity can be destroyed.

A comparative study of New York Harbor and the Thames (London) Estuary (Torpey, 1967) revealed the following sequence of events marking successively more severe conditions resulting from oxygen removal by carbonaceous pollutants:

1) when pollution loading increases to a rate requiring 20 lbs O_2/day/acre instability develops, O_2 level drops sharply, fish migrate

2) at a pollution loading level requiring a rate of 20 to 132 lbs O_2/day/acre the dissolved O_2 remaining substantially constant at between 25 to 50% of saturation. This plateau is homeostatic because symbiotic algae and bacteria are able to maintain this O_2 level.

3) at loading rates exceeding 132 lbs O_2/day/acre the O_2 was exhausted anaerobic conditions obtained.

The waters in the sludge disposal area in the Bight have now reached the last of these phases. Their content of organic matter is extremely high-4.4 to 81.0 mg/1 (Pearce, 1969).

Generally there is a 2 to 13 ppm difference in O_2 concentration between surface and bottom levels. These differences diminish with the breakdown of the thermocline in October-November. Water in the dump area contained

2-3 ppm less dissolved O_2 than water outside the dump area at the same depth. In late July to mid-October the dissolved O_2 level in bottom waters over the sewage sludge dump is frequently less than 2 ppm extending over a distance of several miles. This O_2 level is insufficient to support life (Pearce, 1969).

Figure 27 shows the dissolved oyxgen content of bottom waters of the Bight in August, 1969, while Figure 28 represents a sectional sampling across both dumping areas. It is abundantly clear from these measurements that oxidation of the organic component of the waste consumes the dissolved oxygen, thus reducing the oxygen content of the near-bottom waters in both the spoil and sludge dumping areas (Figure 28). Notice too, the reduction in near-surface water oxygen content by a surface slick, a slick probably traceable to a recent dumping of sludge. Under normal conditions the concentration of dissolved oxygen varies with temperature, salinity, normal biological processes and is strongly dependent on local mixing processes. The seasonal variations in the oxygen content of surface and bottom waters at a location in the center of the sludge disposal area (indicated by the star in Figure 28) is shown in Figure 29. In the sludge disposal area in August-September the oxygen content of the water 3 feet off the bottom falls below the value required for the survival of many marine organisms (Ketchum, 1970a). As a consequence of this oxygen depletion sediment samples collected in the sludge dump area are black and stink of H_2S--characteristic of an environment devoid of oxygen and highly reducing (Pearce, 1969).

The deep waters of the Dead Sea are 5 to 10% saturated with dissolved oxygen (Neev and Emery, 1967) which is roughly the same level as now obtaining in the Bight (Figure 30). Thus if we take the dissolved oxygen content as a measure of the water's ability to support life, the Congressman Ottinger's comparison is an apt one*.

*However, high salt concentration rather than low oxygen concentration is largely responsible for the paucity of life in Dead Sea waters.

In 1948-49 measurements revealed that the oxygen content of the near bottom waters in the dredge and sludge disposal areas were 61 and 50% of saturation respectively. Measurements in July, 1964 about half way between the two disposal areas revealed an oxygen minimum of about 59% or "normal" but in Sept. 1969 a Woods Hole Oceanographic Institution vessel found that the oxygen content in the sludge dump area had fallen to 27% of saturation (Ketchum, 1970b) while the Sandy Hook Laboratory found that in the center of the sewage sludge dump had fallen to 10% of saturation or less.* Evidently, the gross oxygen depletion in the disposal area is a phenomena of recent occurance; that is to say, sometime between 1949 and 1969 dumping activities in the New York Bight exceeded a critical level and became so excessive that the water system could no longer recover from the contaminating perturbation.

"This sequence of events is typical of the trend of pollution problems. Nature has a tremendous capacity to recover from the abuses of domestic pollution so long as the rate of addition does not exceed the rate of recovery of the environment. When this limit is exceeded, however, deterioration of the environment is rapid and sometimes irreversible." (Ketchum, 1970a).

The sediments in the sewage sludge disposal area exhibit very large concentrations of lead, chromium and other toxic heavy metals (Fig. 31,32 and Table 23). Comparison with uncontaminated sediments collected 8 miles eastward indicates that Cr, Pb and Cu are about 150, 300, and 2000 times more contaminated than "normal". (Pearce, 1969; Ketchum, 1970a). The amounts of Cr, Cu and Pb extractable from the sediments increases with increasing conecntration of extracting acid suggesting that the metals are chelated or complexed into organo-

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*It should be noted, however, that there is no evidence either in measurement made in the dump area in 1969 (N. Corwin, Gosnold Cruise 140a) Atlantis Cruise 52, W.H.O.I. ref. no. 70-15 or more recently on Gosnold Cruise 166 (R.F. Vaccaro, private communication, 1971) that the oxygen depletion extends into the water column for more than 5m off the bottom. It also should be noted that the Hudson River is a source of oxygen depleted water. Even in the outer harbor the oxygen content can be as low as 1.8 to 2.0 ppm (Corwin, Ibid.) The river may well be a worse threat to the marine environment than the dump in this regard.

TABLE 23

Heavy Metals in Sediment; (2% HNO_3 Extraction)
(Pearce, 1969)

		Station	Cr	Cu	Pb
	Northern Most	48	0.35 ppm	0.42 ppm	1.30 ppm
		101	0.66	0.028	1.69
		47	0.99	0.016	2.98
		107	0.93	0.052	1.99
	Near North	106	0.70	0.027	1.99
		105	1.12	0.073	5.71
		104	2.04	0.13	6.49
Transect		109	12.3	12.3	30.1
	Sewage Sludge	36	0.66	0.23	1.33
		39	11.9	10.3	26.1
		59	37.9	58.3	151
		70	16.1	35.9	67.9
		63	2.34	0.103	3.58
		53	0.25	0.024	0.55
	Southern	38	0.63	2.87	2.47
		49	1.46	0.43	3.97
		50	1.17	0.318	8.25

metallic complexes and such ecomplexes would be expected to extract into a petroleum phase thus giving rise to this high concentration expecially in the spoil dump sediments. Heavy metals thus extracted and chemicals which can slowly back extract into the overlaying water column or be taken up by organisms and thus be fed continuously into the food chain.

C. Biological Effects

The physical and chemical effects of waste dumping into the waters of the New York Bight are relatively easy to assess - the biological effects will never be completely known. All of us who eat anything from the ocean or who go swimming in the surf are having something chopped off of our life expectancy, as a consequence of ocean dumping. We will never know whether it is only a fraction of a second, a few seconds, a couple of minutes, or perhaps even a day or two. Nevertheless there are some biological effects of the dumping activity which are becoming clear.

With respect to the biological effects of dredge spoils and other solid wastes in areas such as the Delaware and Chesapeake Bays (Cronin *et al.*, 1967; Gunter *et al.*, 1964) there is little evidence and some difference of opinion. A 1965 Corps of Engineers report concluded that it was not possible to assess the effects of the marine disposal of dredged material on the basis of information then available.

Information does exist on the effects of various toxic wastes on fresh water organisms (Hynes, 1963; Klein, 1959, 1962, 1966; Olson and Burgess, 1967) but the relevance of this work to ocean biota is unclear.

Now at the present time, as a consequence of the work of the Sandy Hook Laboratory we have a much clearer idea of the biological damage resulting from dumping operations in the waters of the New York Bight. These preliminary studies have shown that the ecological effects of dredge spoil were similar to those of sewage sludge, but no direct effects were noted in the areas for the disposal of cellar dirt and rubble and acid wastes. The area for the disposal of toxic wastes was not included in the investigation. Pearce (1969) has noted, however, that the biological effects of dredge spoil, while similar to those of the sewer sludge, appear to be even more severe.

The effects on the benthic community has received the most attention. Fish and even plankton are mobile and can move in and out of the polluted area so the possible effects of waste disposal on them is more difficult to evaluate.

The dredge spoil and sewage sludge areaswhich are depleted of dissolved oxygen in the summer months are devoid of any normal benthic populations. At each sludge site the area devoid of life appears to be a circular area of about 2 miles which suggests that the area affected is about 6 square miles. The area in which amphipods (generally more sensitive than most other major benthic organisms) are affected may be considerably larger (Rev. Comm., 1970). Neamtodes, a small marine worm widely distributed in marine sediments, are very tolerant of pollution, yet in the disposal areas even they cannot survive (Figure 32A). Areas peripheral to the sludge dumping ground were either severely impoverished or often dominated by large numbers of _Cerianthus_, a pollution-resistant burrowing sea anemone. Also found were polychaete worms, Rhyuchocoda worms, and the protobranch bivalves, _Yoldia limatulus_ and _Nucula proxima_. Thus in the peripheral areas the indigenous "normal" community is substantially altered. Gammarid amphipods, an important food source for finfish, are highly sensitive to pollution and their numbers were greatly diminished even in the marginally polluted areas. These tube-forming organisms, it might be noted, help to stabilize bottom sediments. Table 24 lists common taxa found in the _Cerianthus_ communities peripheral to the devastated areas. Benthic communities east of the sludge dump are less productive than to the north, west and south-west. But there is no evidence that increased amounts of organic matter above normal background levels has any fertilizing effect on benthic communities (Pearce, 1969).

TABLE 24

A List of the Common Taxa Characteristic of the *Cerianthus* Community Surrounding the Periphery of the Sewage Sludge and Dredge Spoil Disposal Areas (Pearce, 1969)

CNIDARIA
- ANTHOZOA:
  - *Cerianthus americanus*

RHYNCHOCOELA

NEMATODA

ANNELIDA:
- POLYCHAETA:
  - AMPHARETIDAE
  - CIRRATULIDAE
  - COSSURIDAE
  - FLABELLIGERIDAE
  - GLYCERIDAE
  - GONIADAE
  - LUMBRINERIDAE
  - MALDANIDAE
  - NEPHTYIDAE:
    - *Nephtys incisa*
  - NEREIDAE:
    - *Nereis pelagica*
    - *Nereis succinea*
  - PARAONIDAE:
    - *Aricidea jeffreysii*
    - *Paraonis fulgens*
  - SABELLIDAE
  - SPIONIDAE:
    - *Dispio uncinota*
    - *Prionospio malmgreni*
    - *Spiophanes bombyx*
  - TEREBELLIDAE

MOLLUSCA:
- GASTROPODA:
  - *Nassarius vibex*
- BIVALVIA:
  - *Nucuia proxima*
  - *Yoldia limatula*

A number of laboratory tests have been conducted to reveal the response of various animals to the waste contaminated sediments. The mud snail, Nassarius obsoletus, which is highly tolerant and often occurs in polluted waters, avoided sludge contaminated sediment. Similarly hermit crabs, Pagurus congicarpus, avoided the contaminated sediments (Pearce, 1969). The lobsters in unaerated aquaria containing sludge and spoil were dead at the end of 96 hours. In aerated aquaria they remained alive but did develop pathological conditions. In unaerated aquaria without dump sediments they remained alive for an average of 216 hours (Pearce, 1969). Crabs (Cancer irroratus) showed similar behavior with death occurring in 48 hours if the O_2 level was allowed to fall below 2 ppm (Pearce, 1969).

Lobsters, crabs and horseshoe crabs kept for 6 weeks in well aerated aquaria containing sewage sludge developed several pathological anomalies (Pearce, 1969):

1) Severe erosion of the exoskeleton
2) Erosion of chela and pereiopods, especially at the tips
3) Infection of the eyes of the horseshoe crabs with necrotic tissue
4) Fouling of branchial chambers and gills by organic debris, silt, and oil
5) Covering of exposed surface of animals by a layer which could provide an initial residence for the incubation of infective micro-organisms.

Lobsters, it might be noted, while mobile, are fairly stationary residents of the benthic community. They do not make long migrations, rather tending to stay in a limited area (Schroeder, 1959).

Neglecting diseases, Train, Cahn and MacDonald (1970) list four ways by which pollution directly affects marine life:

1) toxicity

2) oxygen depletion

3) biostimulation

4) habitat changes

With respect to biostimulation (3) fertilization of waters from sludge can cause excessive blooms of algae (biostimulation) and the debris from this upon settling to the bottom can change the nature of the sediments and second affect benthic forms. Oyxgen depletion is the most important, with perhaps toxicity occupying second place, but, quite apart from these chemical effects, even if the waste materials were inert, they could still create havoc. Even with no toxicity or oxygen consumption, there will be deleterious effects simply from the "physical dislocation of bottom dwellers subjected to repeated burial episodes" (Oviatt, 1968).

The area where dredge waste disposal has an appreciable effect on biota cover 7 mi^2 (or 18 km^2) (Pearce, 1969), the 5,700,000 m^3 of wastes deposited each year between 1964 and 1968 corresponds to an accumulation of about 32 cm/yr., while the sewage sludge deposition of 150,000 m^3/yr. over an area of 14 m^2 (36 km^2) corresponds to about 4 mm/yr. (Gross, 1970b.) An accumulation as great as 30 cm/yr may be great enough to exterminate certain benthic organisms simply by burial. And, even apart from physical burial, high turbidity in natural waters can be detrimental to aquatic life (Hollis, et al., 1969). Saila et al.(1968) list nine indirect effects of turbidity and siltation on aquatic biota:

1) reduction in light penetration and reduced photosynthesis.

2) reduction of visibility to some feeding organisms.

3) destruction of spawning areas

4) reduction of food supplies.

5) reduction of vegetational cover
6) trapping of organic matter, resulting in anerobic bottom conditions.
7) flocculation of planktonic algae.
8) absorption or adsorption of organic matter or inorganic ions.
9) absorption of oil.

They add that some possible beneficial effects are nutrient enrichment and improved substrate conditions for certain economically important organisms. The direct effects of turbidity and siltation involve suffocation or impairment of respiratory exchange for both fish and shellfish, as well as reduced growth and survival of larval life history stages of fish and shellfish. Davis (1960) and Loosanoff (1962) determined the direct effect of turbidity on eggs, larvae, and adults of some pelecypod mollusks. It appears from these studies that larval and adult pelecypods may be very adversely affected by 3000-4000 ppm of fine sediment (Saila et al., 1968).

Further the sewage sludge contains a high percentage of small particles while the dredge spoil show a wide range of particle size. Both are very dissimilar to the natural sandy sediments lying outside of the polluted area. Benthic fauna are highly dependent on the nature of the bottom sediments (Sanders, 1958), thus the wastes probably adversely effect bottom dwellers in this way in addition to simple burial and bottom instability.

Plankton are of extreme importance because of their most strategic position in the chain of life in the oceans, and, unfortunately the effects of the dumping operations on plankton are unclear. The Review Committee (1970) found that the limited data do "not clearly show any direct effects of the disposal operations" on zooplankton population (see Figure 33). But filtered bottom water collected from the sewage sludge dump area completely inhibited phytoplankton cell growth and photosynthesis (Pearce, 1969). The natural productivity of the waters in the disposal area was probably about 100 g C/m^2 (ocean surface)yr, (Ryther, 1969), taking the disposal area 125 km^2 (35 naut. mi^2) about 12,000 metric tons of carbon per year would normally be produced, yet disposal operations are putting about 100,000 metric tons of carbon per year into the waters. As we have seen, the oxygen content of the waters is insufficient to enable them to cope with this additional burden of oxidizable carbon.

Preliminary analyses indicate that heavy metals may be getting into the water column and zooplankton. Since the areas where the concentrations of heavy metal are high are devoid of benthic life, the danger of the passage of these toxic elements into the food chain is slight but this may not be true of the surrounding peripheral areas (Peter, 1970). Because of the relatively rapid circulation in the area, however, and the mobility of zooplankton, it is difficult to draw unambiguous conclusions.

In his press release of February 11th, 1970, the Congressman Ottinger charged that the dumping operations threatened coastal fish such as weakfish, croakers, bluefish, and fluke; that if the contamination spreads to the Hudson Canyon it could bar access of anadronous fish to the Hudson River thus threatening stripped bass, sturgeon, and shad; that ocean fish such as tuna will be driven out to sea away from present fisheries; and that migrating fish may spread contamination and disease to adjacent Atlantic coast fisheries. Now it is inconceivable that the dumping operations are not effecting finfish, but it is most unclear on the basis of existing information just what and how important these effects might be. The most tangible evidence unearthed to date appears to be a high incidence of fin rot originated in or near the contaminated areas of the Bight (Rev. Comm., 1970). "The causal relationship is not yet proven, but if the disease is directly associated with the sewage sludge disposal operation and carried to other areas by migrating fish, the effects of this sewer sludge disposal may be much more widespread than the small areas which can be directly identified as effected". (Ketchum, 1970). Jeffries (1968), however, has noted that this infection can perhaps be caused simply by restricting the movement of the animals.

Pearce (1969) records that the finfish population in the sewage sludge dump varies with the seasonal fluctuations in the dissolved oxygen content.

A few other possibly relevant bits of information might be inserted here. Fine suspended solid matter adversely effects, sometimes lethally, the gill epithelium of fish (Klein, 1962) and similar deleterious effects are expected for invertebrates, especially filter feeders.

Acid waste concentrations greater than 1:600 (acid to sea water) were fatal to the white mullet, _Mugil curema_; greater than 1:1000 fatal for the common solvessede, _Menidia menidia_ (Pearce, 1969). Incineration residues did not effect the fatty acid content of samples taken from winter flounder (_Pseudopleuronectes americanus_), (Jeffries, 1968).

On the basis of a preliminary check on New York fishery landings we thought we saw some evidence that pollution of the Bight was adversely affecting fisheries. A more careful examination of this data source, however, with the assistance of W. E. Steinhauer of this laboratory, failed to yield any unambiguous conclusions (The Review Committee (1970) reached an identical finding). In 1969 compared with the previous year there was a 32% reduction in quantity and 2% decline in value of New York landings (Anon., New York Landings, 1969). (Table 2). Careful analysis of New York Landings statistics from 1961 to 1969 showed that although the catch of some species have declined over recent years (Tables 2,25, Figure 34) others have increased. Also notice that in Figure 34 the biggest decline in catch is in New York Marine District Area 5 (Figure 35) rather than, as one might expect in Area 1 which includes the waters of the Bight where the decline over the period 1966 to 1969 is relatively modest. The failure of these statistics to throw light on possible pollution effects is clear--there are far too many other factors which effect the catch. For example the catch in Area 1 is dominated by whiting which in December 1969, even although being less than half its 1968 value (Table 25) represented about 83% of the total catch. This catch is subject to the usual natural fluctuation and is a seasonal one. Far more important, since 1963 Soviet vessels have efficiently fished whiting waters further out to sea. By 1965 they were removing some 300,000 metric tons of fish per year and by 1967 had seriously depleted the fish population in the entire area (Graham (1968)). Except in cases where specific piscatory diseases such as fin rot are in evidence, against a background of such enormous population perturbations, it becomes almost futile to speculate upon the adverse effect of pollution of the Bight waters on fish populations.

The catch decline in a single year (such as 1966, due to weather conditions) can be much greater than the total average decline over several years, again illustrating that natural factors and/or fishing practice can make changes far outweighing the influence of pollution.

There does seem to be a gradual overall decline in fish landing over the last half dozen years, but it is extremely difficult to unravel how much of this is due to pollution, to fishing out by foreigners, to the decline of our own fishing fleet, and to countless other factors still unsuspected.

Petrochemicals, as noted above can effect marine organisms by 1) their inherent toxicity, 2) their ability to concentrate pesticides, and 3) their ability to concentrate toxic metals. The concentration of pesticides in dredge spoil by oil may even be beneficial since it may serve to scavange pesticides from the upper part of the water column where they can seriously interfere with

TABLE 25
New York Landings by Area, December, 1968
(Preliminary)

Species	Area 1 Ocean, New Jersey Boundary To East Rockaway	Area 2 Ocean, East Rockaway Inlet To Jones Inlet	Area 3 Ocean, Jones Inlet To Moriches Inlet	Area 4 Great South Bay	Area 5 Ocean, Moriches Inlet To Shinnecock Inlet
Fish	Pounds	Pounds	Pounds	Pounds	Pounds
Anglerfish	-	-	-	-	1,400
Butterfish	495	-	1,174	-	-
Cod	2,625	15,900	5,670	-	8,000
Eels, Common	3,000	-	-	2,400	-
Flounders, Blackback	6,887	2,900	3,400	400	6,000
Yellowtail	5,250	16,500	53,725	-	44,700
Fluke	-	-	-	-	1,600
Hake, Red (Ling)	19,575	47,825	2,485	-	2,975
Herring, Sea	425	-	-	-	-
Mackerel	1,800	1,400	-	-	-
Scup or Porgy	-	-	-	-	1,475
Sharks, Grayfish (Dogfish)	600	500	-	-	1,900
Skates (Rajafish)	-	-	564	-	-
Striped Bass	-	-	-	-	500
Whiting	238,040	98,625	12,286	-	24,600
White Perch	-	-	-	-	-
Unclassified, for food	7,250	2,450	1,220	-	3,500
Total Fish	285,947	186,100	80,524	2,800	96,650
Shellfish					
Lobsters, Northern	2,000	2,000	-	-	-
Clam Meats: Hard	-	-	-	311,952	-
Soft	-	-	-	256	-
Surf	18,989	38,250	219,351	-	-
Oyster Meats	-	-	-	1,425	-
Scallop Meats, Edible, Bay	-	-	-	6,000	-
Squid	-	-	-	-	4,000
Total Shellfish	20,989	40,250	219,351	319,633	4,000
Grand Total	306,936	226,350	299,875	322,433	100,650

TABLE 25 (Continued)
New York Landings by Area, December 1969
(Preliminary)

Species	Area 1 Ocean, New Jersey Boundary To East Rockaway	Area 2 Ocean, East Rockaway Inlet To Jones Inlet	Area 3 Ocean, Jones Inlet To Moriches Inlet	Area 4 Great South Bay	Area 5 Ocean, Moriches Inlet To Shinnecock Inlet
Fish	Pounds	Pounds	Pounds	Pounds	Pounds
Anglerfish	1,500	500	-	-	2,500
Butterfish	3,895	-	1,417	-	-
Cod	10,137	-	15,694	-	19,075
Eels, Common	1,300	-	-	2,575	-
Flounders: Blackback	-	-	1,240	1,200	28,000
Yellowtail	41,030	23,750	12,300	-	32,000
Fluke	-	-	-	-	1,900
Hake, Red (Ling)	47,385	15,500	1,527	-	1,440
Herring, Sea	4,500	2,000	4,650	-	-
Mackerel	2,260	4,100	-	-	-
Scup or Porgy	-	-	-	-	5,400
Sea Bass	-	100	-	-	500
Sharks, Grayfish (Dogfish)	-	1,500	-	-	3,000
Skates (Rajafish)	1,075	-	100	-	-
Whiting	116,944	91,250	7,210	-	17,850
White Perch	-	-	-	-	-
Unclassified, for food	6,515	5,000	1,250	-	2,500
Total Fish	236,552	143,700	45,388	3,775	114,165
Shellfish					
Lobsters, Northern	2,700	1,800	-	-	-
Clam Meats: Hard	-	-	-	371,028	-
Surf	13,464	39,100	243,814	-	-
Mussel Meats, Sea	-	-	-	-	-
Oyster Meats	-	-	-	510	-
Scallop Meats, Edible, Bay	-	-	-	6,285	-
Squid	-	-	353	-	8,400
Total Shellfish	16,164	40,900	244,167	377,823	8,400
Grand Total	252,716	184,600	289,555	381,598	122,565

photosynthesis. With respect to heavy metals their toxicity is well known. Copper for example, is the active ingredient in many anti-marine-fouling preparations. Copper is present in the waters of the New York Bight in concentrations greater than 0.120 mg/l. Laboratory experiments show that

Cu conc. of 0.1 mg/l kill soft clams in 10-12 days

Cu cons. of 0.05 mg/l kill polychaete worms in 4 days

Cu. conc. of 0.1 mg/l inhibit phytosynthesis in kelp 70% in 9 days

While sublethal doses of copper reduce growth rates and reproduction in fishes (Train, Cahn and Mac Donald, 1970).

The effects of incinerator ash residue on selected marine species have been studied (Oviatt, 1968). Residue concentrations up to 10% by weight gave no significant size or weight changes and no mortalities on 90-day bioassays on quahaug (Merenaria merenaria) bioassays, nor concentrations up to 30% on 40-day bioassays on the common mummichog (Fundulus heteroditus). Residue concentrations above 5% by weight caused a significant mortality in winter flounder. First and second stage lobster larvae (Homarus americanus) and the common prawn (Palemonetes vulgaris) were easily able to withstand residue concentrations of 1%. Juvenile menhaden (Brevootia tyrannus) were the most sensitive fish species tested. Of all the species tested the sea scallops (Pecten magellanicus) showed the highest sensitivity (Oviatt, 1968).

The heavy metal concentrations in the above incinerator residue were

Fe	40,000 ppm
Zn	5,000
Pb	4,000
Cu	1,000
Mn	700
Ni	70
Cr	60
Co	20
Cd	10

Table 26 gives the Cr, Cu and Pb content of the tissues of two animals examined by Pearce (1969). He notes that inasmuch as the area where the concentrations of these metals are the highest are devoid of life there is little danger that these metals will pass into the food chain, but that this is <u>not</u> true of the peripheral zones surrounding the devastated area. We also mentioned above that some havey metals seem to be taken up by zooplankton.

TABLE 26

Preliminary Studies of Heavy Metals in Tissues of Various Animals, Using a 50% HNO_3 Extraction. (Pearce, 1969)

	actual ppm wet weight extracted		
	Cr	Cu	Pb
Neanthes	1.35	0.62	3.6
Cyprina icelandica	1.7	0	7.4
FWPCA Manual Concentration	0.2 - 1.0	4 - 50	0.5

The toxicity of these metals may also do considerable indirect damage to the environment by substantially reducing the "normal" rate of waste decomposition by inhibiting microbiological processes (Ketchum, 1970b).

Clams harvested in the Bight for sale contain coliform bacteria levels 50 to 80 times greater than FDA standards, while in 1961 an outbreak of infectious hepatitis was traced to raw shellfish taken from adjacent Raritan Bay (Train, Cahn and MacDonald, 1970). Even in the marginally polluted areas 5 miles from the center of the disposal area, more than 80% of the surf clams examined had excessive coliform levels (King, 1970). It is difficult to determine the level of bacterial infection of organisms in the most polluted areas of the dumps since these areas are devoid of living organisms (Pearce, 1969), however Table 27 presents some coliform counts on sediment samples taken in and near

TABLE 27

Analysis of Sediments for Bacterial Contamination
(Public Health Service Data)

(Pearce, 1969)

Station No.	Location	MPN	
		Total Coliform	Fecal Coliform
59	Center of dump	35,000	7,900
70	Slightly E. of Center	160,000	22,000
63	6 miles E. of Center	490	78
48	6 miles N. of Center (off Long Island)	330	20
36	6 miles W. of Center (off Sandy Hook)	380	
49	5 miles S. of Center	78	20
53	9 miles E. of Center	20	20
50	10 miles SE. of Center	20	20

the dump area. Fecal bacteria discharged into the sea disappear more rapidly than expected on the basis of dilution only. In agreement with the earlier findings of ZoBell (1936) and Carpenter *et al*. (1938) (see also Ketchum, Carrey and Briggs, 1947) Carpenter, Carter and Whaley (1967) found a kill of over 99.97% of coliform bacteria in sea water in slightly over 3 hours after discharge. There was, however a rather disturbing aftergrowth between 5 and 6 hours. Nusbaum and Garver (1955) on the other hand state that coliform organisms can "persist in sea water for relatively long periods". Figure 36 shows the coliform field near the Hyperion sewer outfall. Previously it was proposed that sea water had bactericidal properties, now, however, it appears that aggregation, settling and adsorption also may be important processes in reducing the bacterial level.

King (1970) has summarized the effects of sewer sludge (SS) and dredge spoil (DS) disposal on the New York Bight ecosystem in the dump areas as follows:

Environment

1. Greatly reduced levels of dissolved oxygen in the bottom waters (SS,DS) .
2. Abnormally high concentrations of heavy metals (Pb, Cr, Cu) in the sediments (SS,DS).
3. Drastic changes in the physical properties of the sediments, e.g. particle size and cohesiveness (SS,DS).
4. Unusually high percentage of hydrophobic materials in the sediments (DS).
5. Greatly increased concentration of organic matter in the sediments (SS,DS).

Biota

1. Complete absence of benthic macrofauna in center of areas (SS,DS).
2. Characteristic communities of resistant benthic macrofauna in the marginally polluted areas (SS).

FIGURE 1

The location of various waste disposal sites in the New York Bight (Ketchum, 1970)

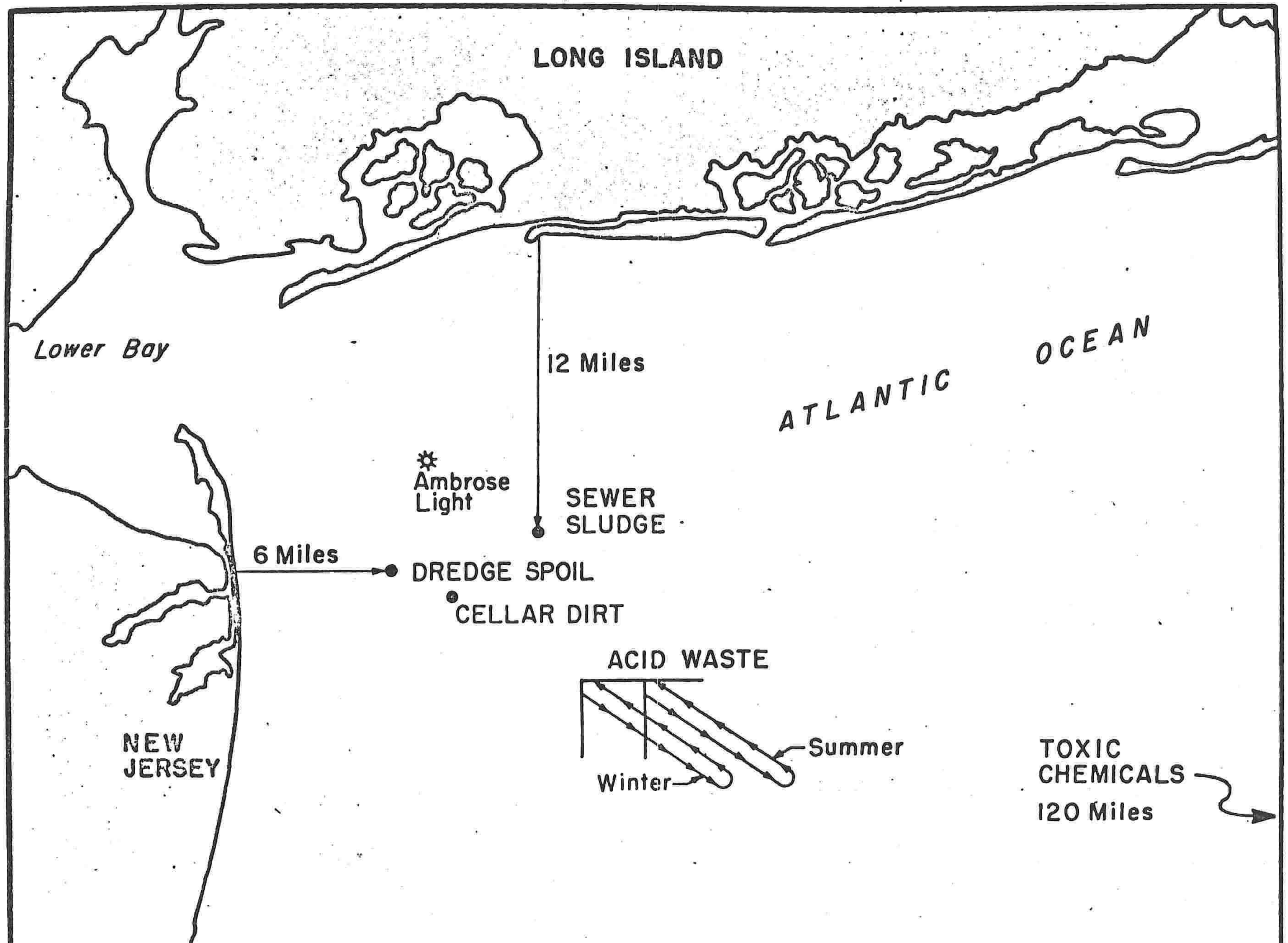

LONG ISLAND
Lower Bay
12 Miles
ATLANTIC OCEAN
Ambrose Light
SEWER SLUDGE
6 Miles
DREDGE SPOIL
CELLAR DIRT
ACID WASTE
Summer
Winter
NEW JERSEY
TOXIC CHEMICALS
120 Miles

FIGURE 1

FIGURE 2

Location of disposal sites used for wastes coming from the New York Metropolitan Region (Gross, 1970b)

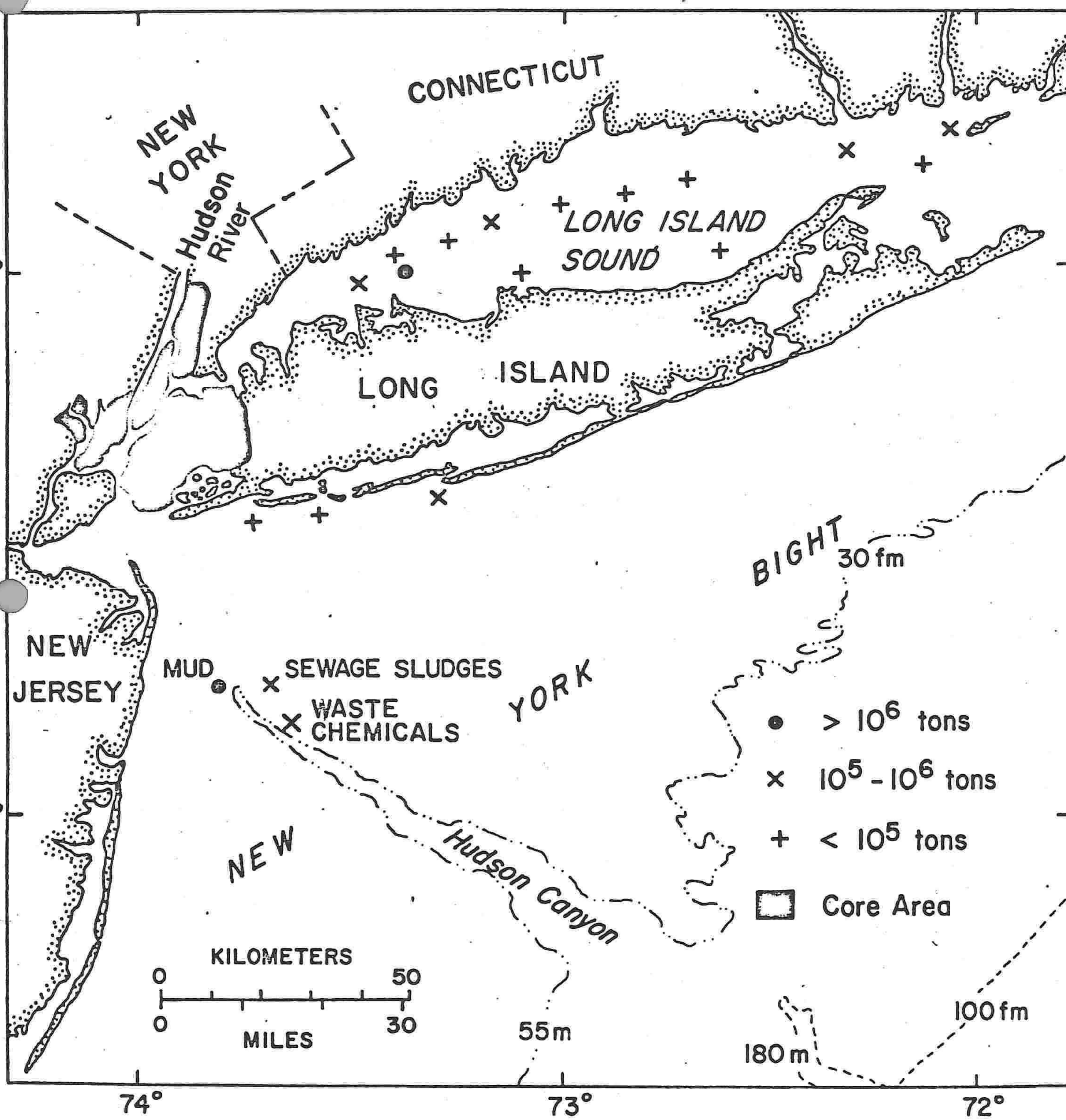

CONNECTICUT
NEW YORK
Hudson River
LONG ISLAND SOUND
LONG ISLAND
1°
0°
BIGHT
30 fm
NEW JERSEY
MUD
SEWAGE SLUDGES
WASTE CHEMICALS
NEW YORK
> 10^6 tons
10^5 - 10^6 tons
< 10^5 tons
Core Area
Hudson Canyon
KILOMETERS
0
50
0
30
MILES
55m
180 m
100 fm
74°
73°
72°

FIGURE 2

FIGURE 3

Bottom Topography of the New York Bight

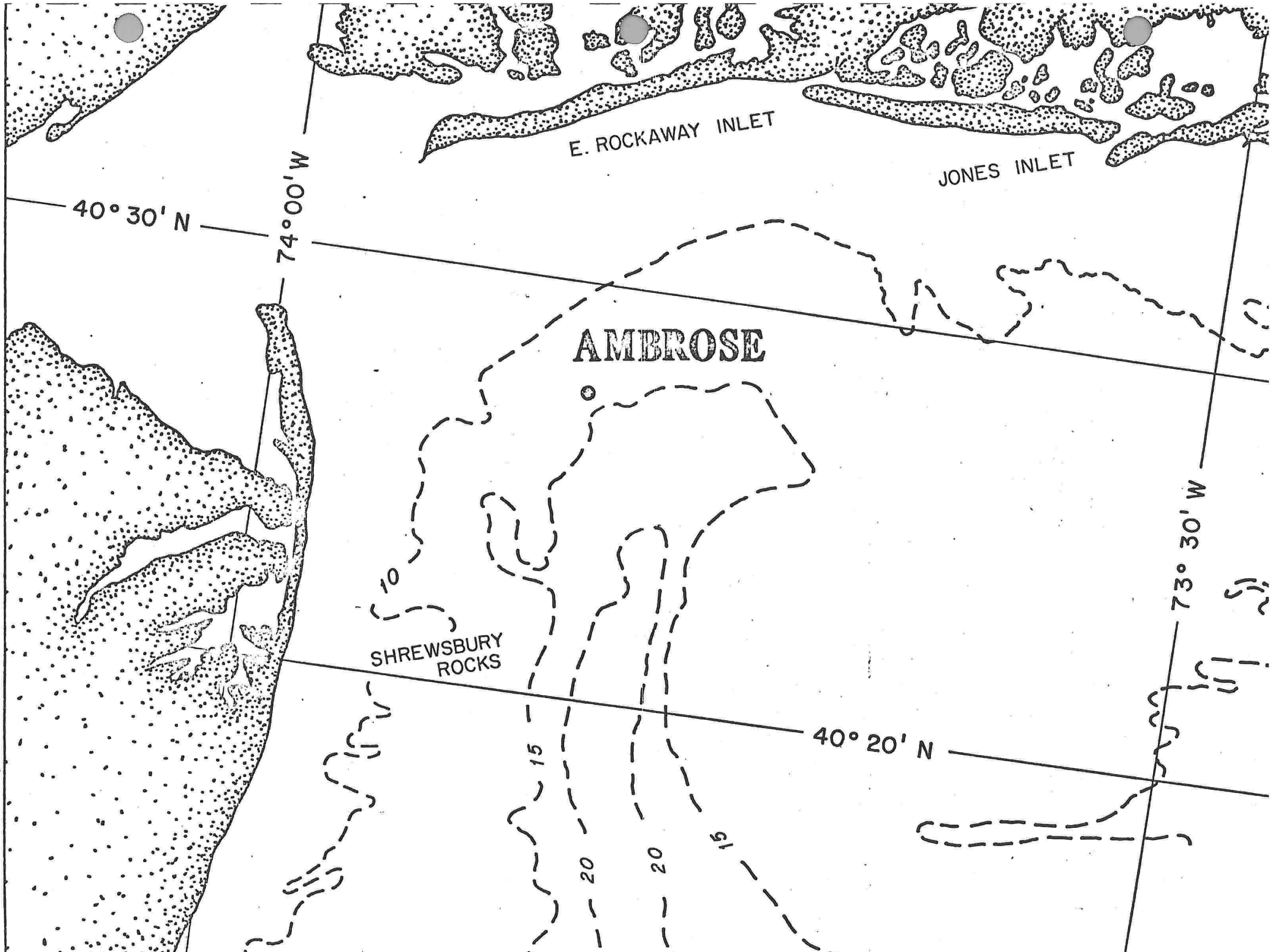

E. ROCKAWAY INLET
JONES INLET
40° 30' N
74° 00' W
AMBROSE
73° 30' W
10
SHREWSBURY
ROCKS
40° 20' N
15
20
20
15

FIGURE 3

FIGURE 4

Winter Surface Curculation (Bumpus and Lauzier, 1965).

FIGURE 5

Spring Surface Circulation (Bumpus and Lauzier, 1965)

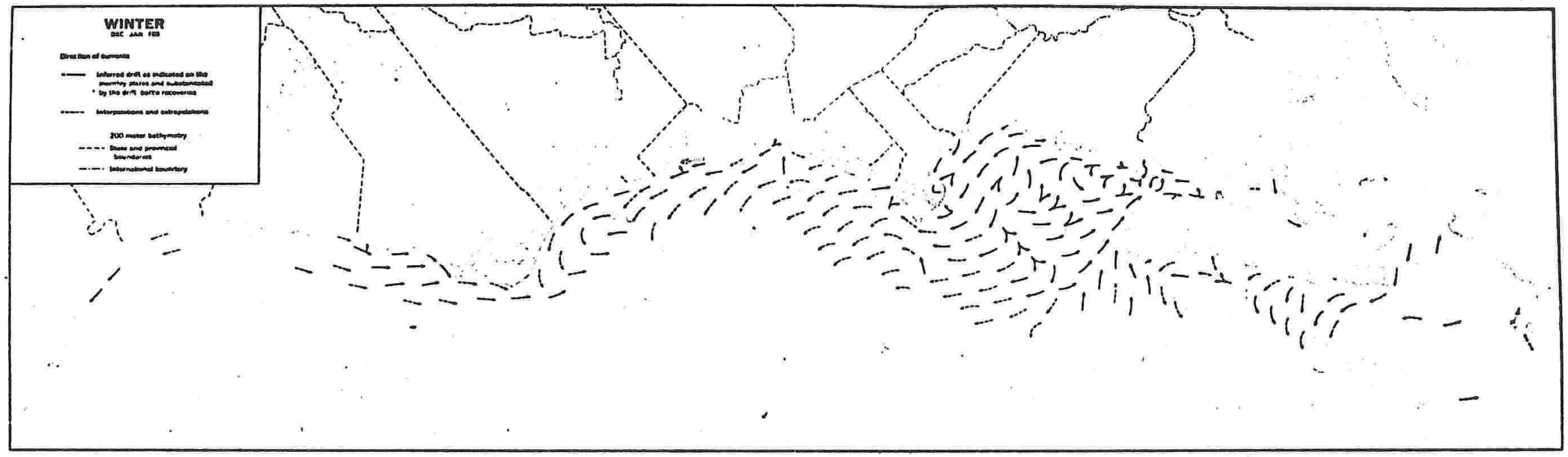


FIGURE 4

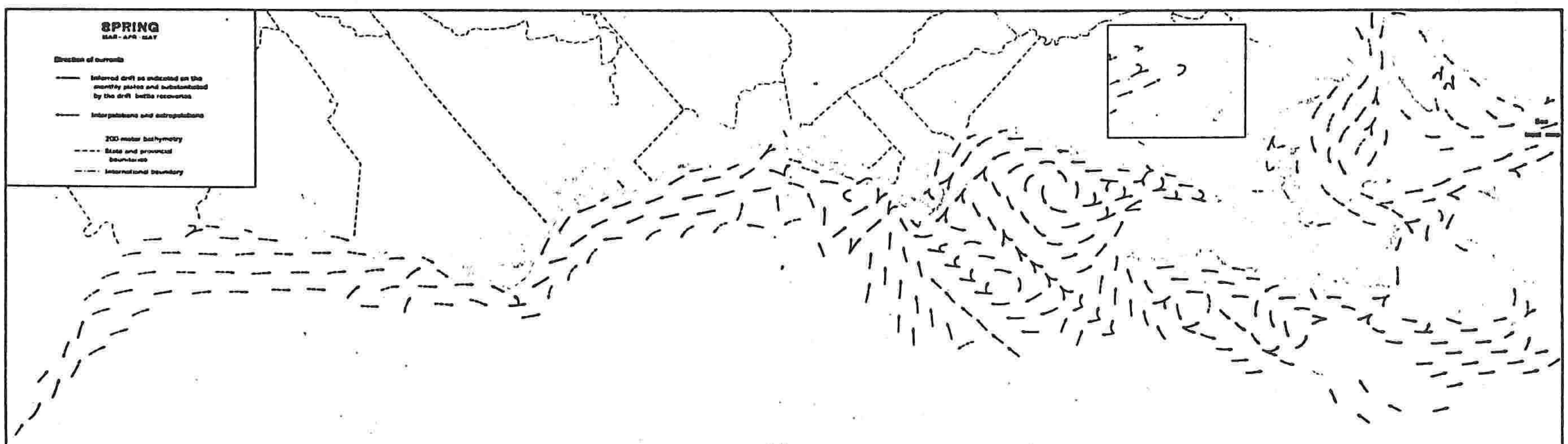


FIGURE 5

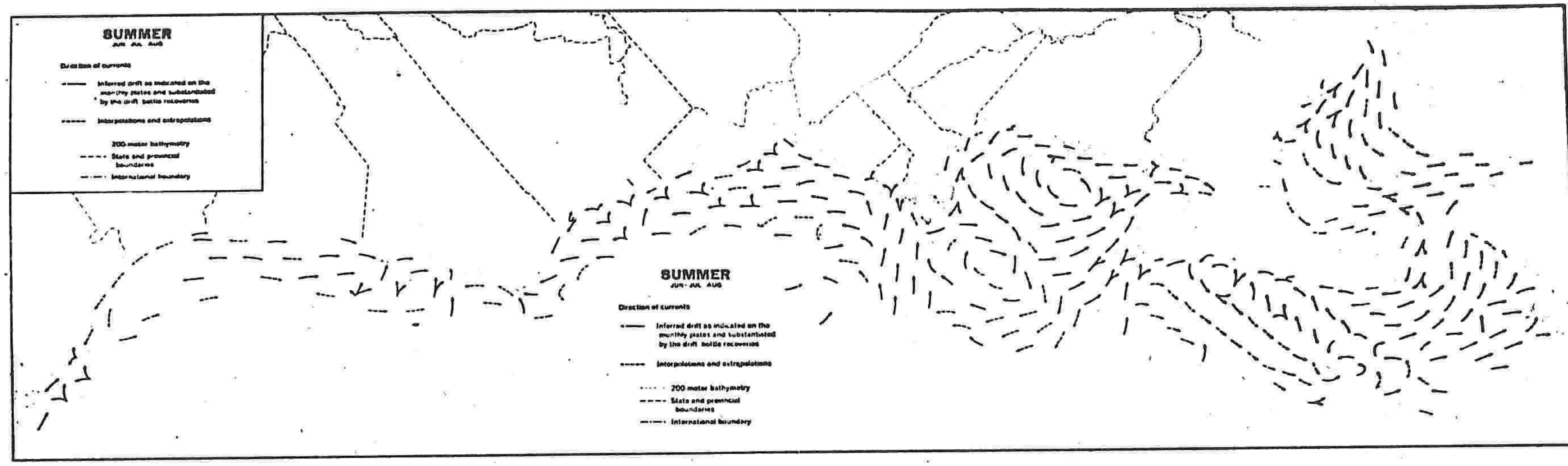
FIGURE 6

Summer Surface Circulation
(Bumpus and Lauzier, 1965)

FIGURE 7

Autumn Surface Circulation
(Bumpus and Lauzier, 1965)

FIGURE 6



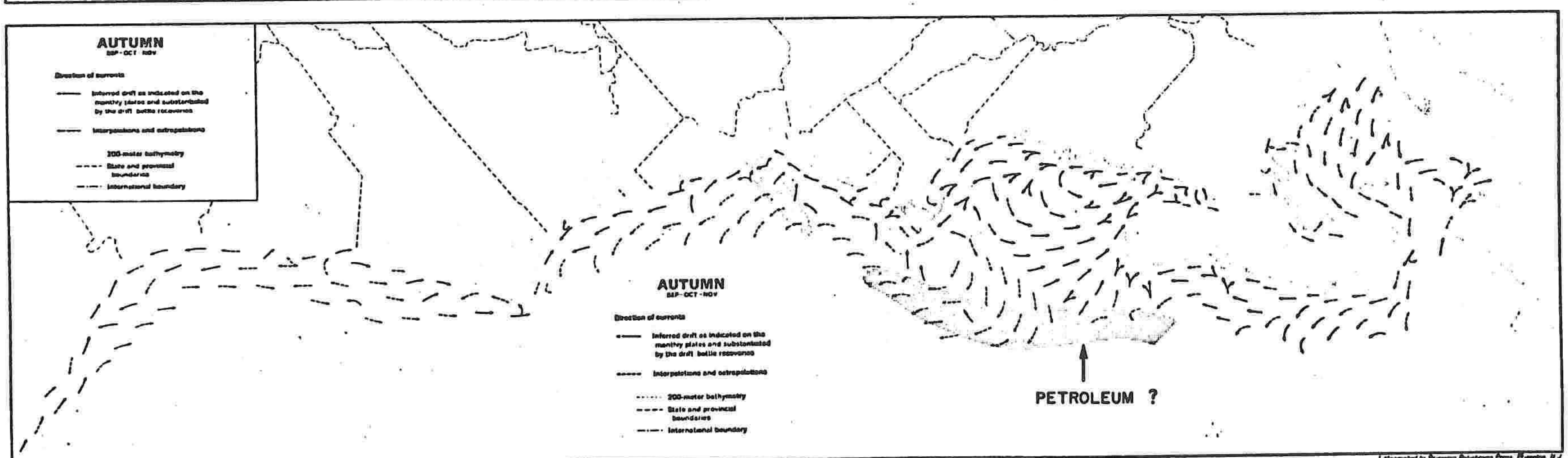


FIGURE 7

FIGURE 8

Reconstructed Trajectories of Drift Bottles
Summer, 1951 (Powers, 1953)

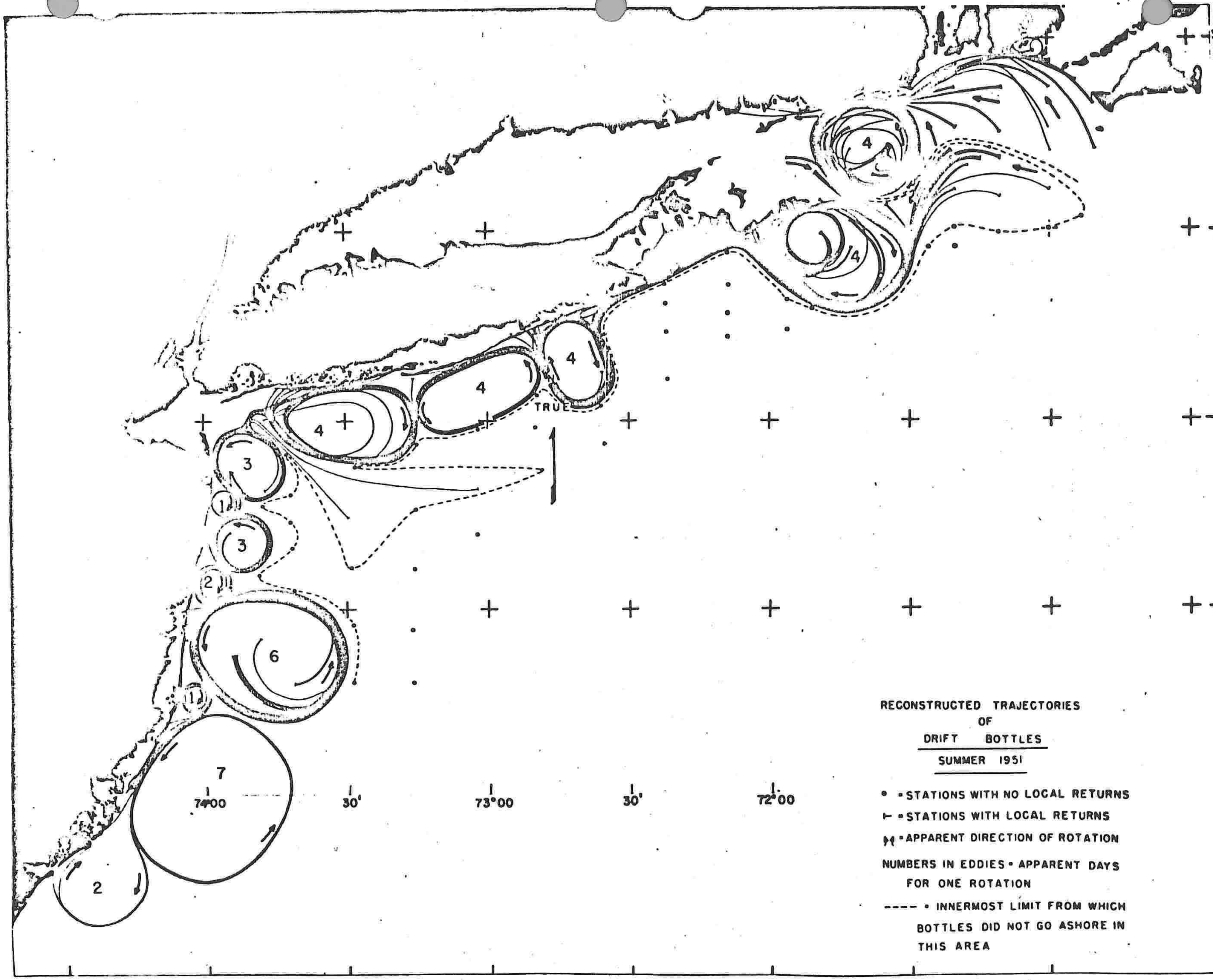

RECONSTRUCTED TRAJECTORIES
OF
DRIFT BOTTLES
SUMMER 1951
• = STATIONS WITH NO LOCAL RETURNS
⊢ = STATIONS WITH LOCAL RETURNS
= APPARENT DIRECTION OF ROTATION
NUMBERS IN EDDIES = APPARENT DAYS FOR ONE ROTATION
---- = INNERMOST LIMIT FROM WHICH BOTTLES DID NOT GO ASHORE IN THIS AREA
TRUE
74°00
30'
73°00
30'
72°00
30'
41° 00
30'
40° 00
4
4
4
4
4
3
1
3
2
6
1
7
2

FIGURE 8

FIGURE 9

Surface Drifter Returns, June
(Pearce, 1969)

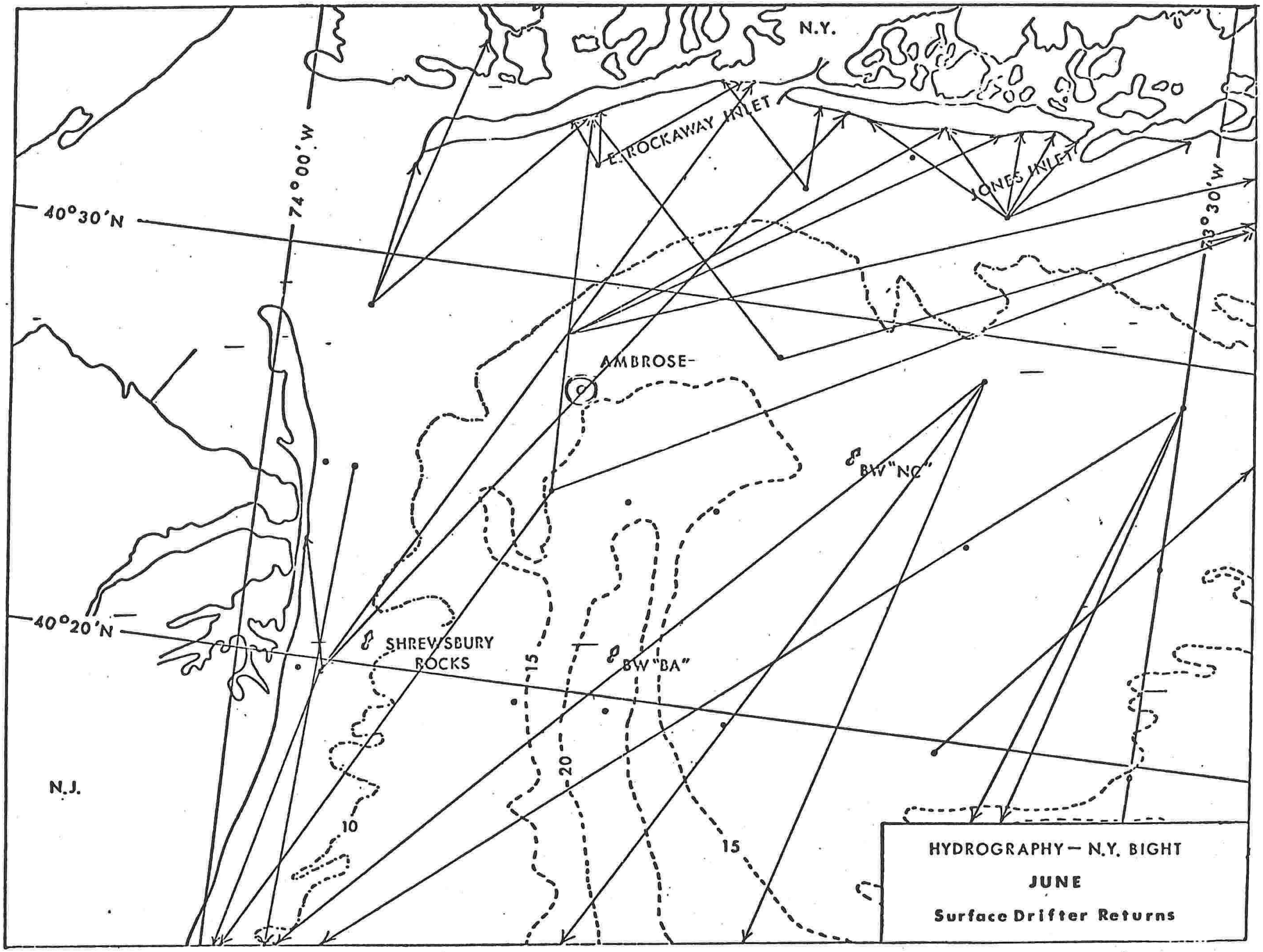

N.Y.
E. ROCKAWAY INLET
JONES INLET
74°00'W
73°30'W
40°30'N
40°20'N
AMBROSE
SHREWSBURY ROCKS
BW "NC"
BW "BA"
N.J.
10
15
20
15
HYDROGRAPHY — N.Y. BIGHT
JUNE
Surface Drifter Returns

FIGURE 9

FIGURE 10

Sea Bed Drifter Returns, October
(Pearce, 1969)

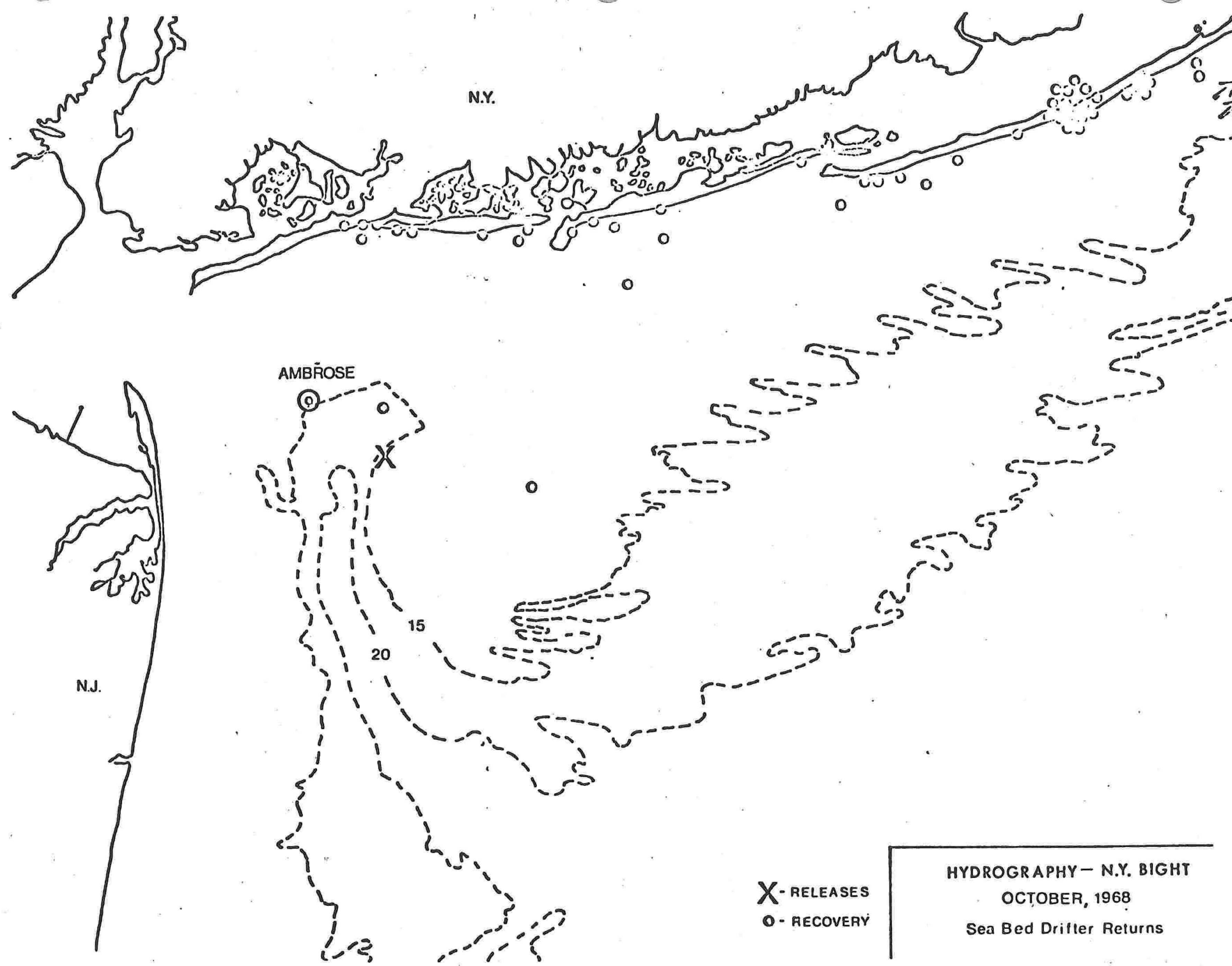

N.Y.
AMBROSE
15
20
N.J.
X - RELEASES
O - RECOVERY
HYDROGRAPHY — N.Y. BIGHT
OCTOBER, 1968
Sea Bed Drifter Returns

FIGURE 10

FIGURE 11

HYDROGRAPHY-N.Y. BIGHT

JUNE

Sea Bed Drifter Returns

(Pearce, 1969)

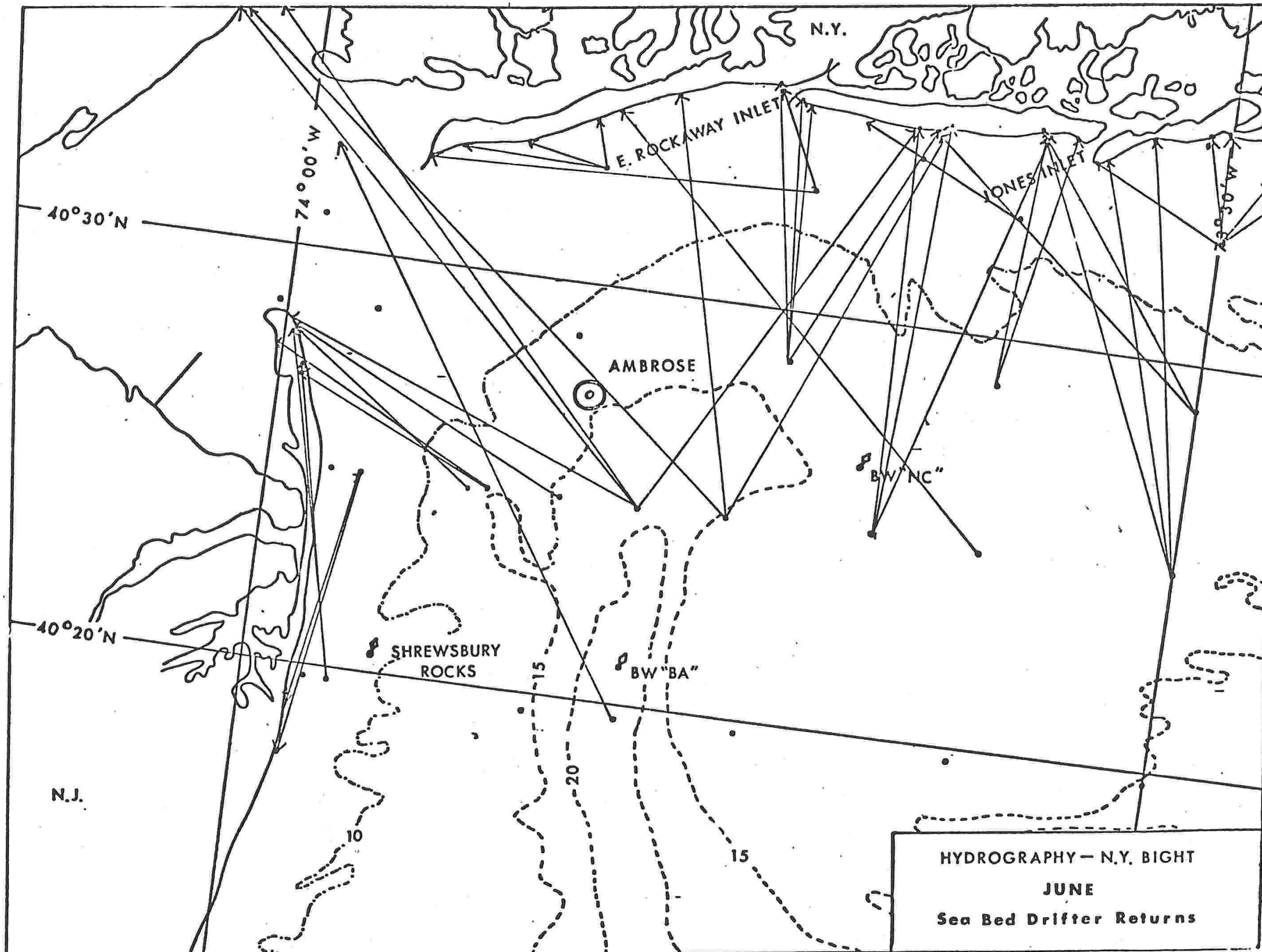

N.Y.
E. ROCKAWAY INLET
JONES INLET
40°30'N
74°00'W
AMBROSE
BW "NC"
SHREWSBURY
ROCKS
BW "BA"
40°20'N
N.J.
10
15
20
15
HYDROGRAPHY — N.Y. BIGHT
JUNE
Sea Bed Drifter Returns

FIGURE 11

FIGURE 12

Schematic representation of net currents in Raritan and Lower Bays. (Jeffries, 1962)

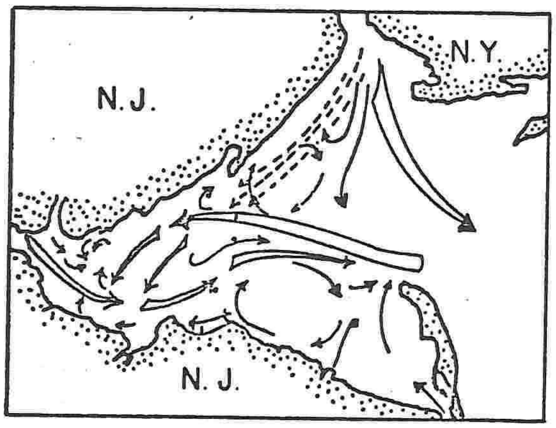
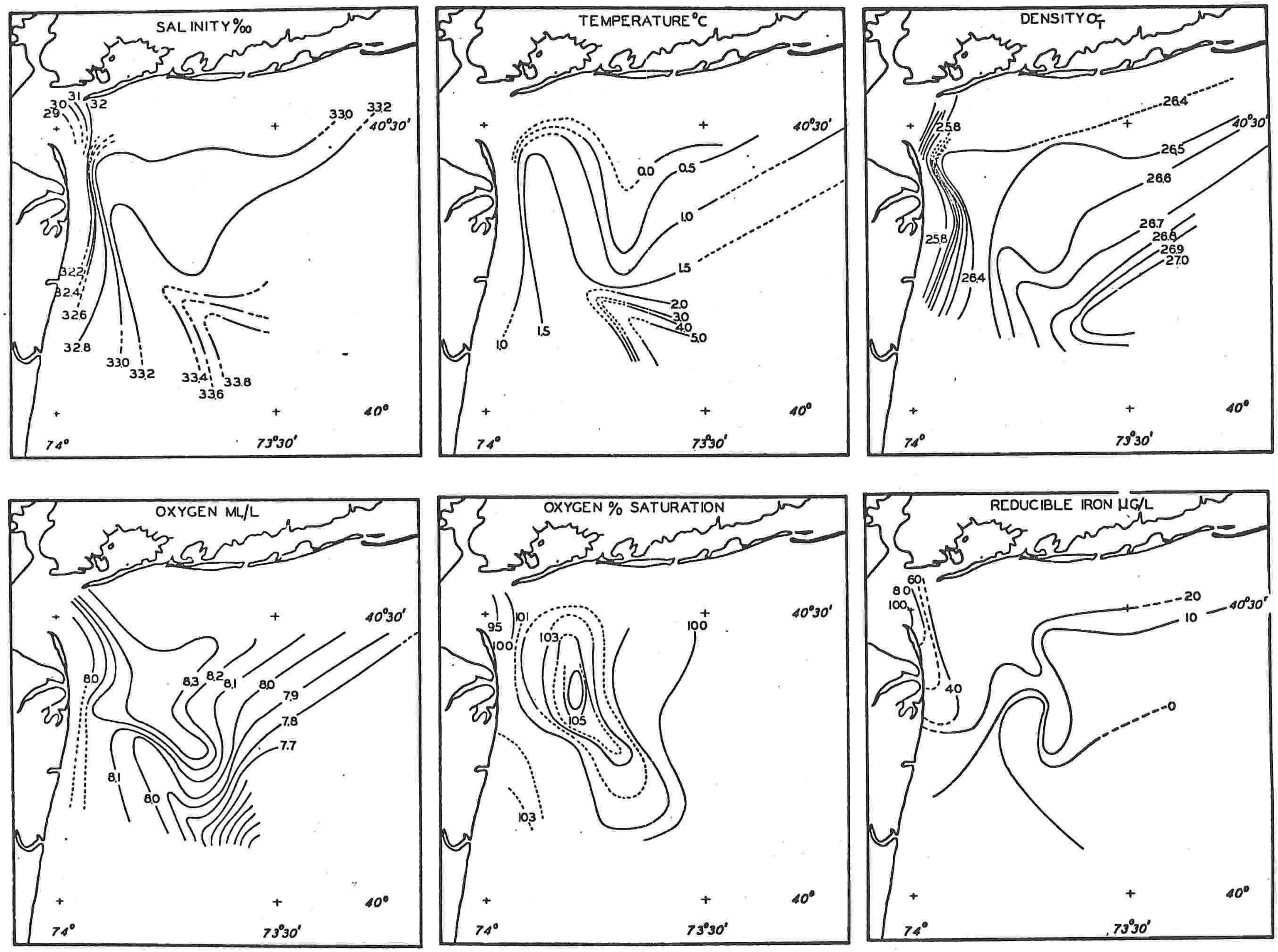


FIGURE 12

FIGURE 13

Surface distribution of properties in February, 1948. (Ketchum, _et.al._, 1951)



SALINITY ‰
TEMPERATURE °C
DENSITY σ_T
OXYGEN ML/L
OXYGEN % SATURATION
REDUCIBLE IRON µG/L
74°
73°30'
40°
40°30'

FIGURE 13

FIGURE 14

Vertical distribution of properties in February, 1948. The vertical distortion in this, and in subsequent comparable figures, is about 1:400. (Ketchum, _et.al._, 1951)

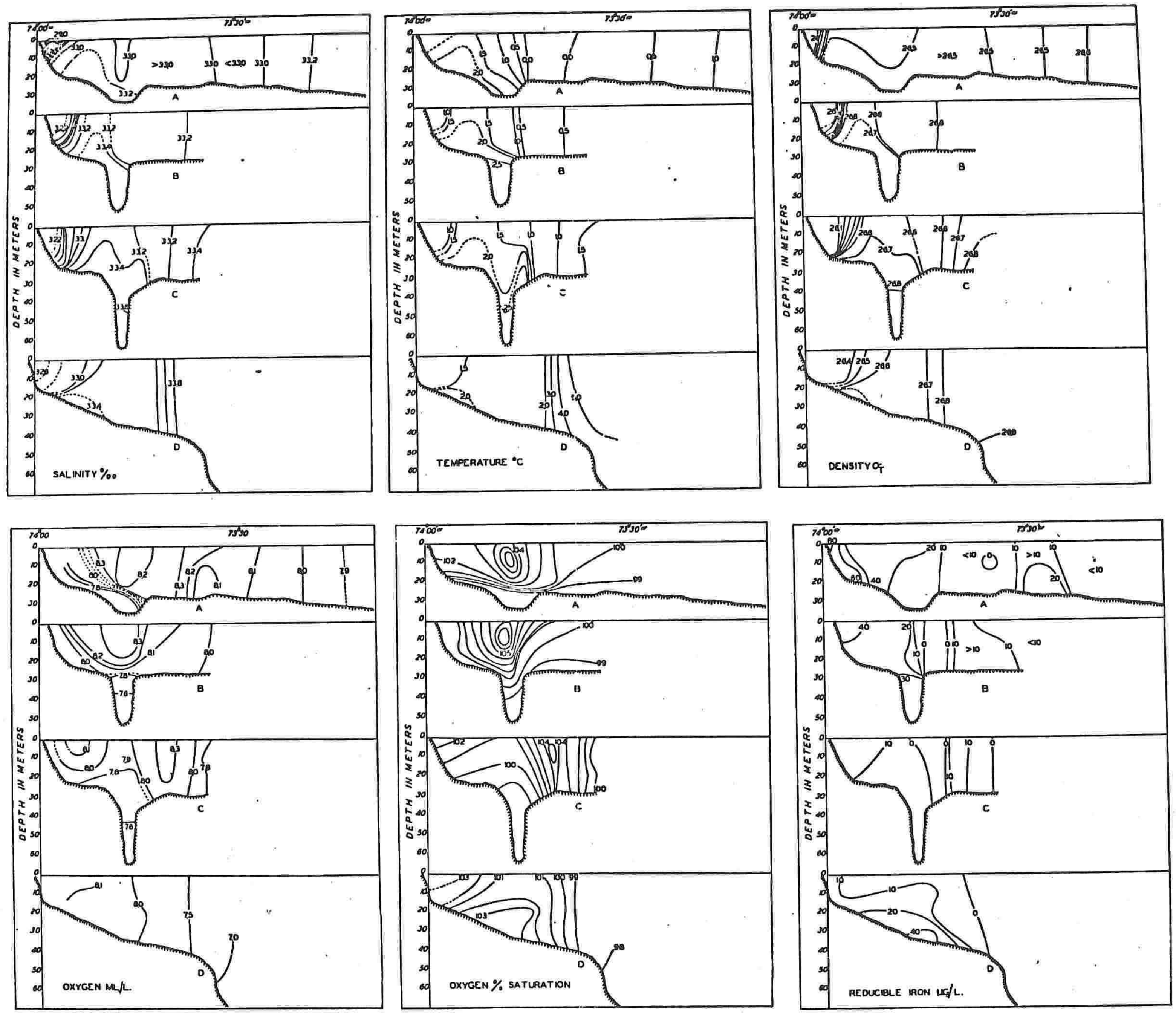
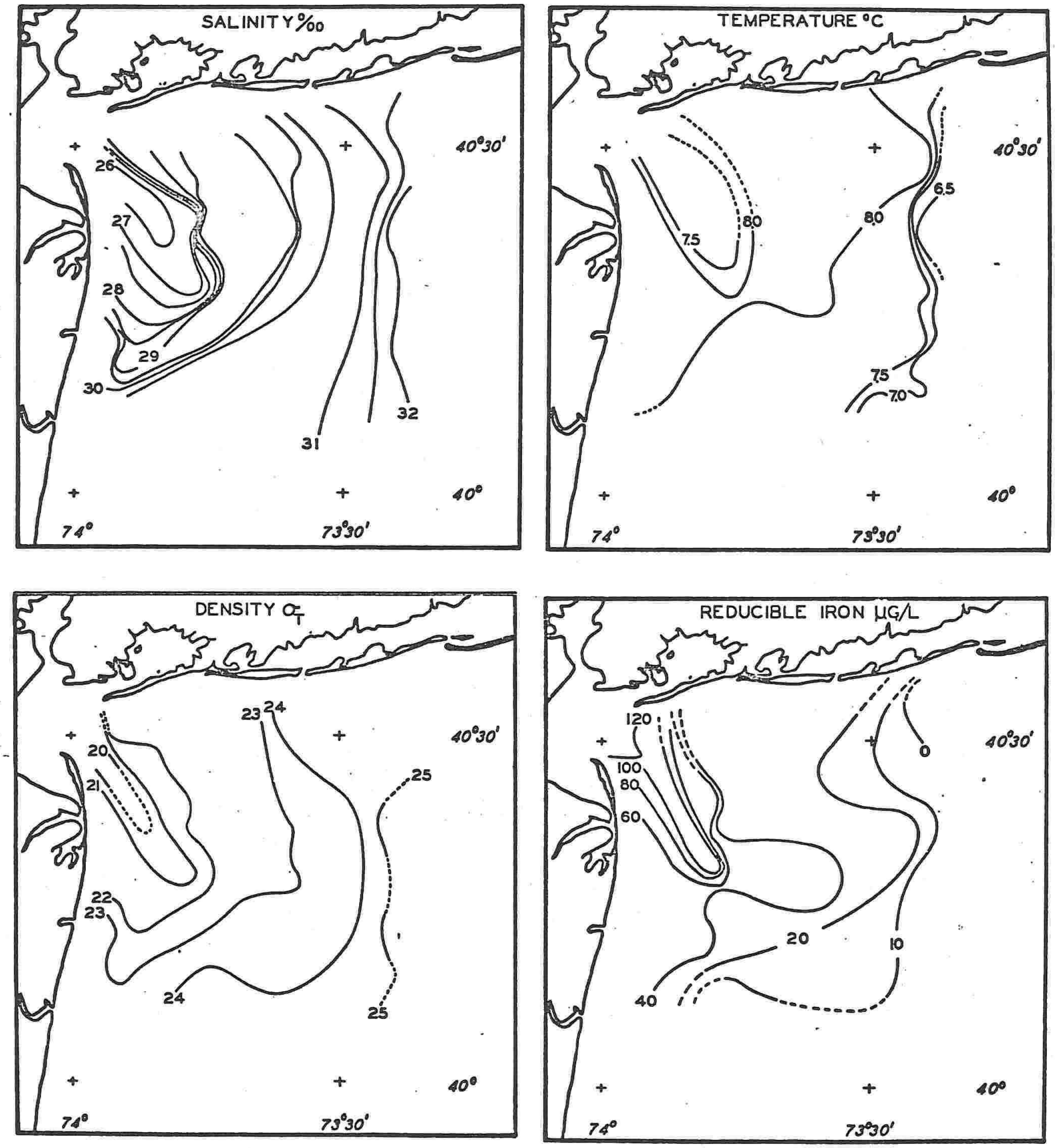

DEPTH IN METERS
SALINITY ‰
TEMPERATURE °C
DENSITY σT
OXYGEN ML/L.
OXYGEN % SATURATION
REDUCIBLE IRON µG/L.

FIGURE 14

FIGURE 15

Surface distribution of properties in April, 1948. (Ketchum, et.al., 1951)

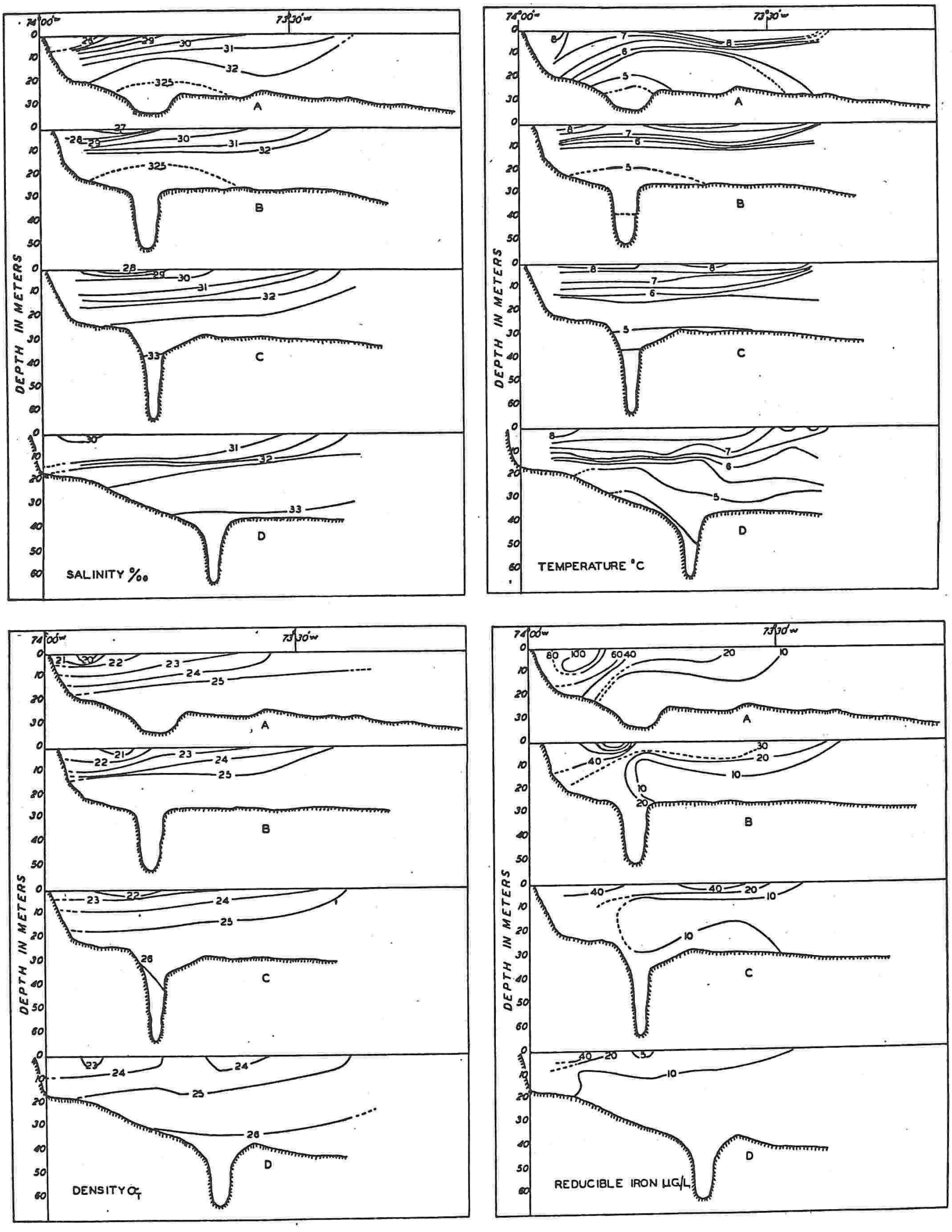


SALINITY ‰
26
27
28
29
30
31
32
40°30'
40°
74°
73°30'
TEMPERATURE °C
7.5
8.0
8.0
6.5
7.5
7.0
40°30'
40°
74°
73°30'
DENSITY σT
20
21
22
23
23
24
24
25
25
40°30'
40°
74°
73°30'
REDUCIBLE IRON µG/L
120
100
80
60
40
20
10
0
40°30'
40°
74°
73°30'

FIGURE 15

FIGURE 16

Vertical distribution of properties in April, 1948. (Ketchum, *et.al.*, 1951)



SALINITY ‰
TEMPERATURE °C
DENSITY σ_T
REDUCIBLE IRON µG/L
DEPTH IN METERS
74°00'W
73°30'W
A
B
C
D

FIGURE 16

FIGURE 17

Surface distribution of properties in October, 1948. (Ketchum, _et_._al_., 1951)

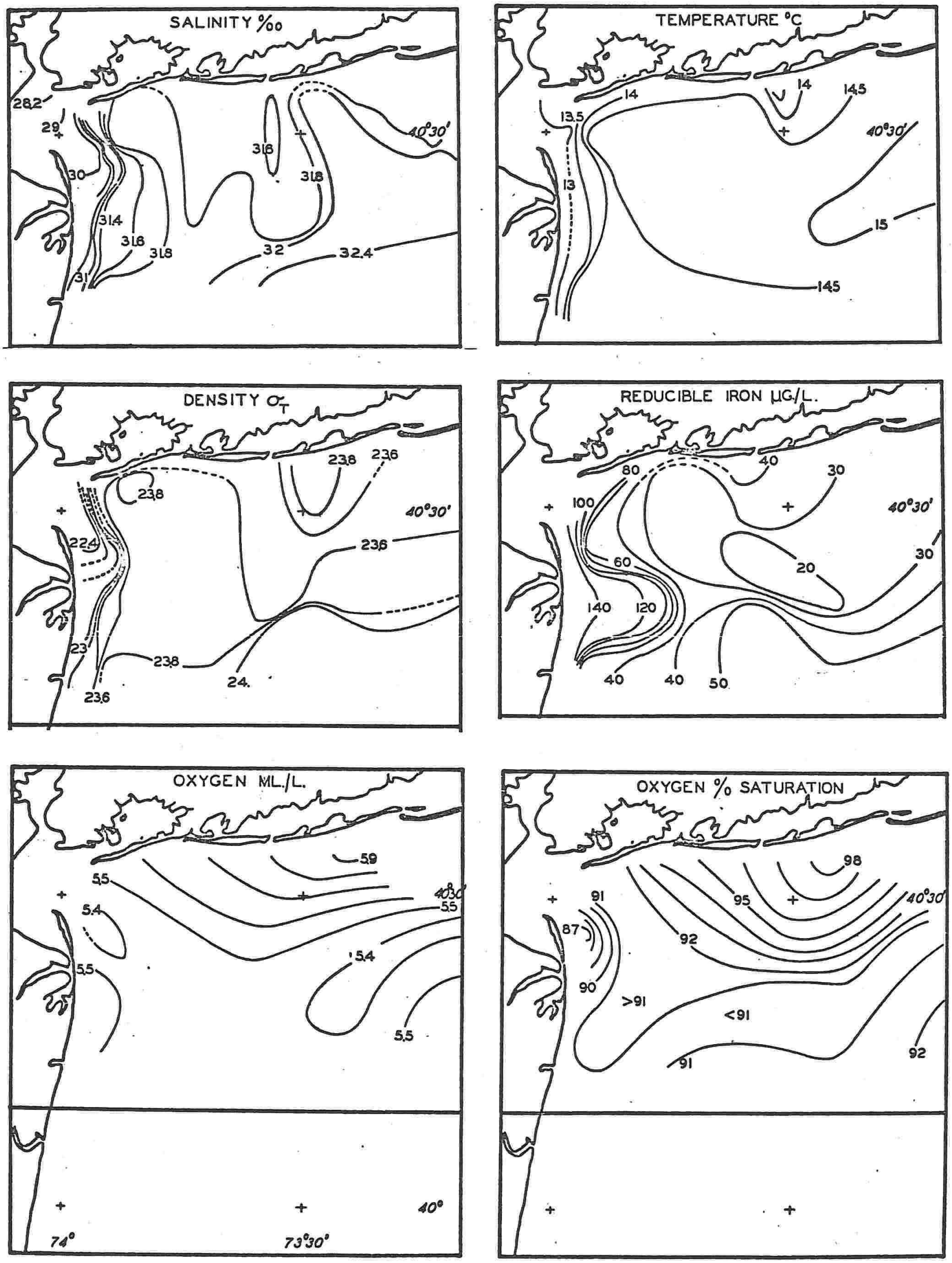

SALINITY ‰
28.2
29
30
31.4
31.8
31.8
31
31.6
31.8
32
32.4
40°30'
TEMPERATURE °C
14
14
14.5
13.5
13
40°30'
15
14.5
DENSITY σ_T
23.8
23.6
23.8
40°30'
22.4
23.6
23
23.8
24.
23.6
REDUCIBLE IRON µG./L.
40
30
80
100
40°30'
30
60
20
140
120
40
40
50
OXYGEN ML./L.
5.9
5.5
40°30'
5.5
5.4
5.4
5.5
5.5
OXYGEN % SATURATION
98
91
95
40°30'
87
92
90
>91
<91
91
92
40°
74°
73°30'

FIGURE 17

FIGURE 18

Vertical distribution of properties
in October, 1948. (Ketchum, *et. al.*, 1951)

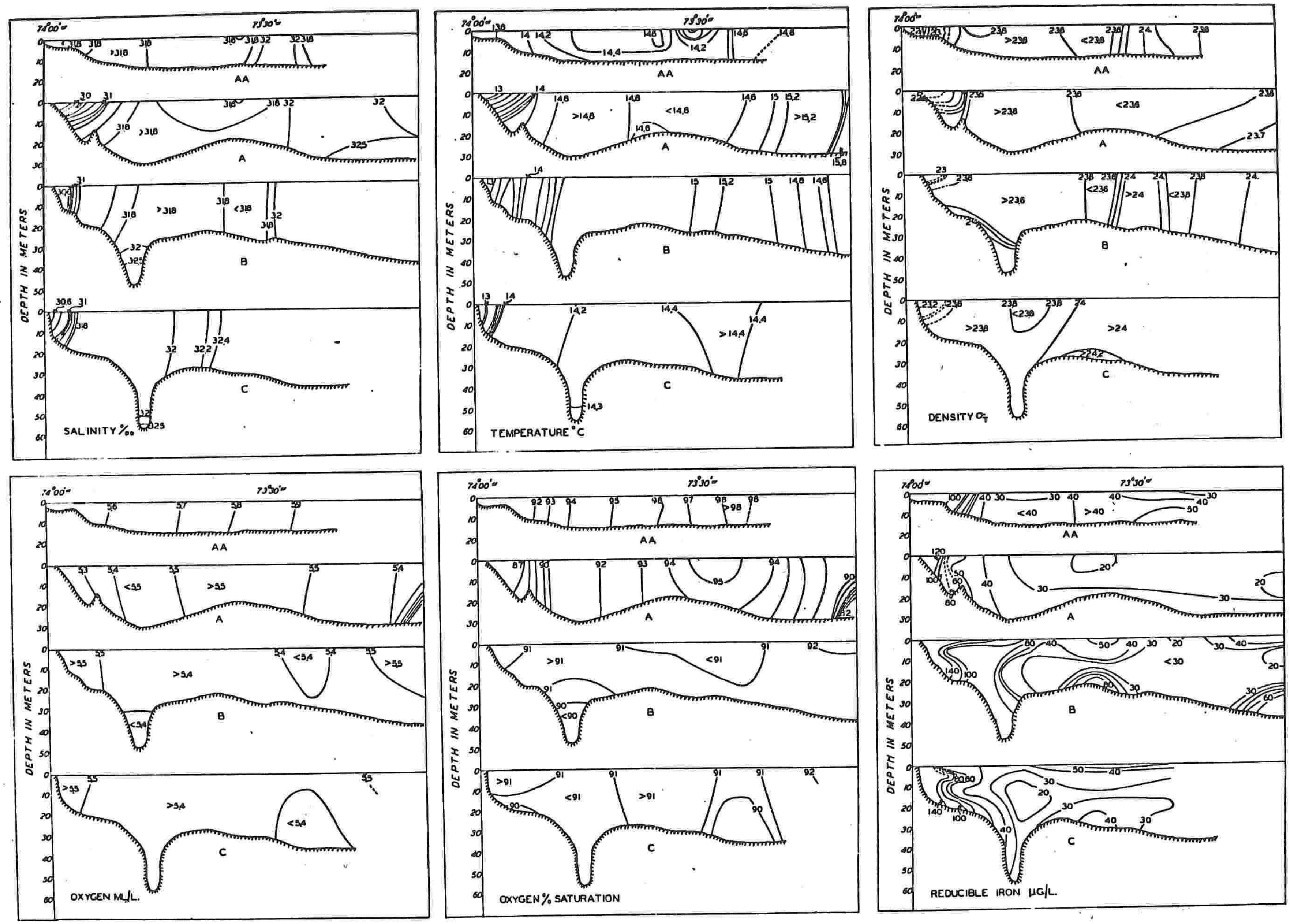

74°00'
73°30'
DEPTH IN METERS
AA
A
B
C
SALINITY ‰
TEMPERATURE °C
DENSITY σ_T
OXYGEN ML/L.
OXYGEN % SATURATION
REDUCIBLE IRON μG/L.

FIGURE 18

FIGURE 19

Seasonal variation of properties at the station near Scotland Lightship and at the station in the southeast corner of the area. Solid circles - surface; open circles - bottom. (Ketchum, et.al., 1951)

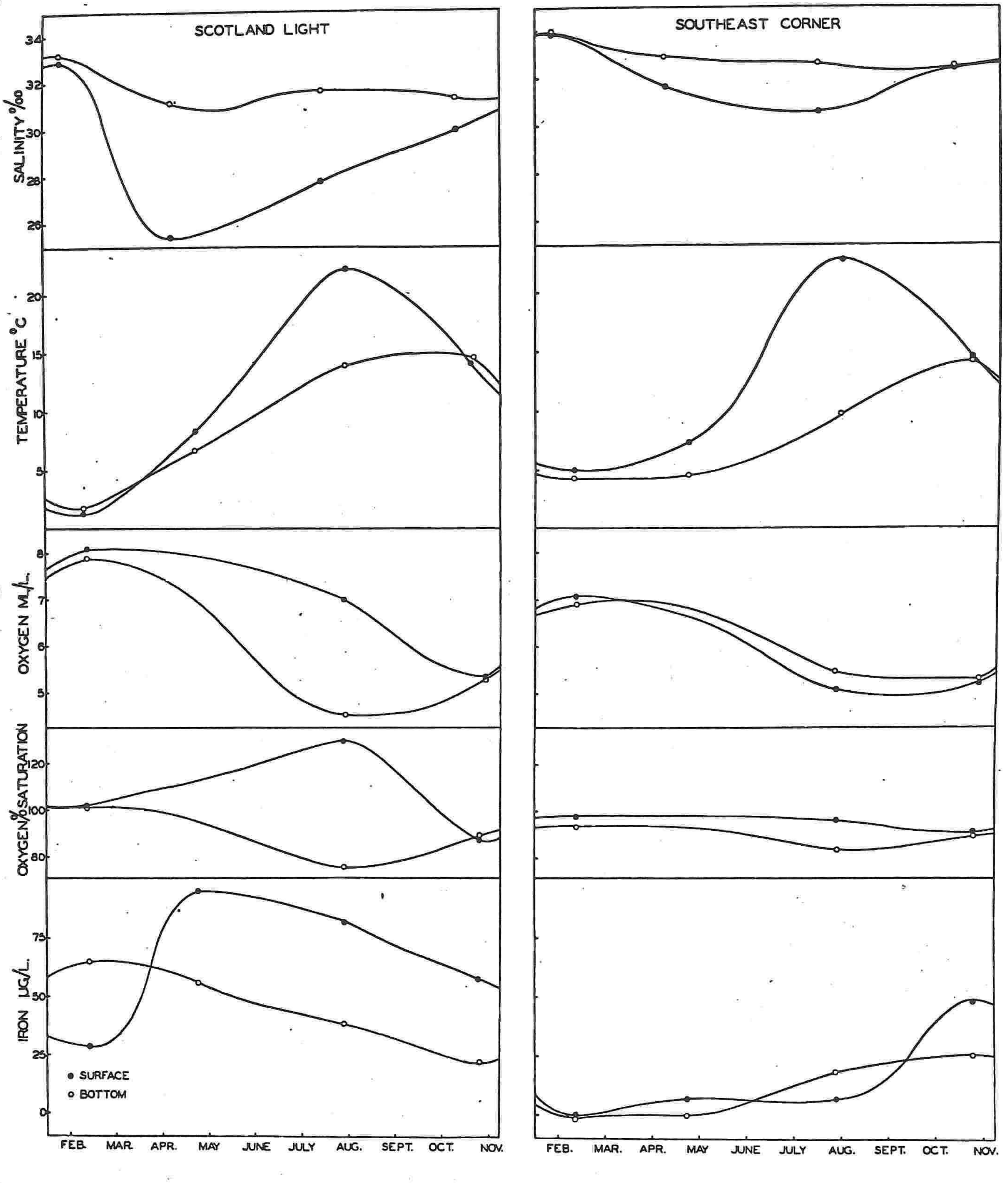

SCOTLAND LIGHT
SOUTHEAST CORNER
SALINITY ‰
TEMPERATURE °C
OXYGEN ML/L.
OXYGEN % SATURATION
IRON µG/L.
SURFACE
BOTTOM
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.

FIGURE 19

FIGURE 20

Surface Salinity June 5-6, 1969

(Pearce, 1969)

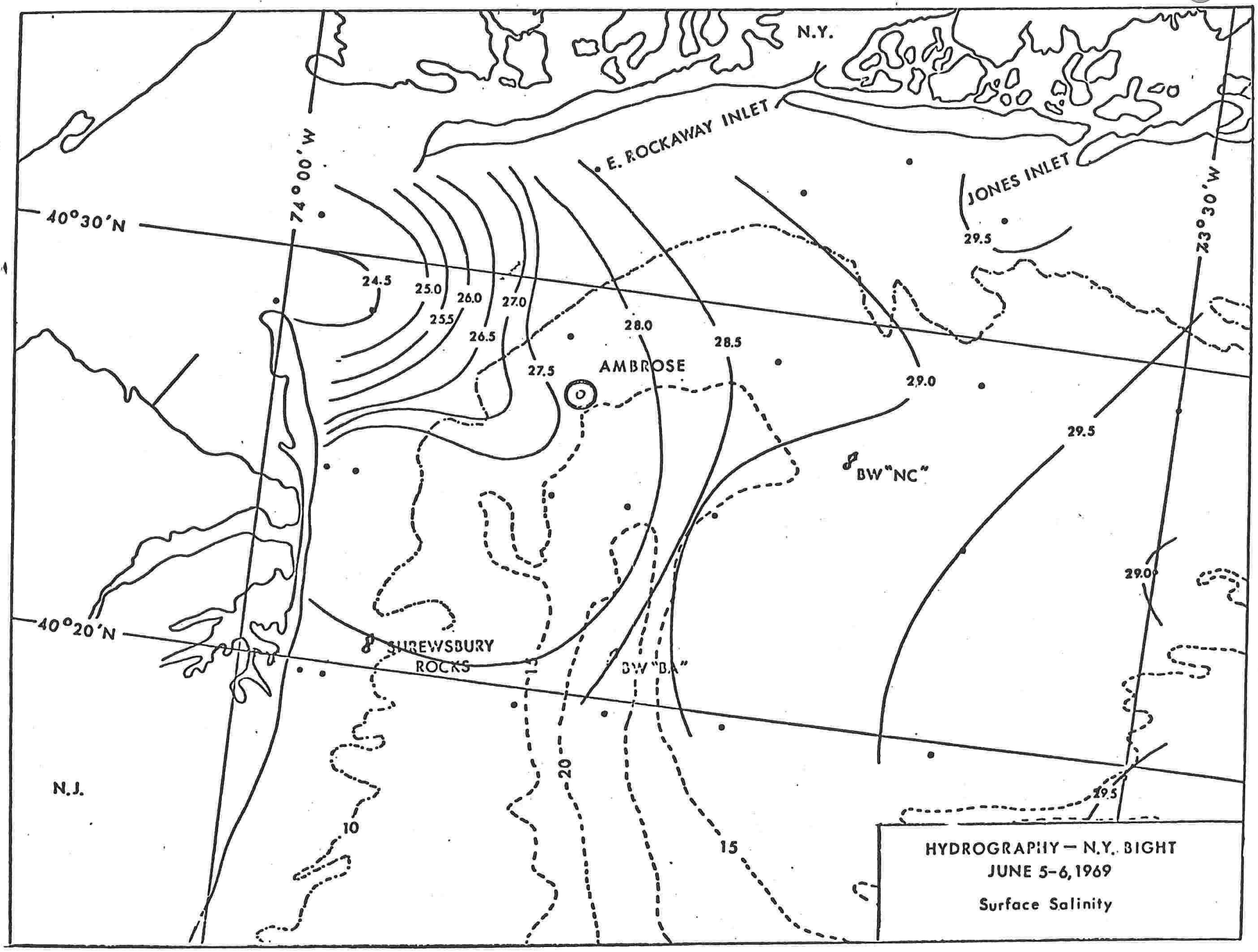

HYDROGRAPHY — N.Y. BIGHT
JUNE 5-6, 1969
Surface Salinity
N.Y.
N.J.
E. ROCKAWAY INLET
JONES INLET
AMBROSE
BW "NC"
BW "BA"
SHREWSBURY ROCKS
40°30'N
40°20'N
74°00'W
73°30'W
24.5
25.0
25.5
26.0
26.5
27.0
27.5
28.0
28.5
29.0
29.5
10
15
20

FIGURE 20

FIGURE 21

Bottom Salinity, June 5-6,1969
(Pearce, 1969)

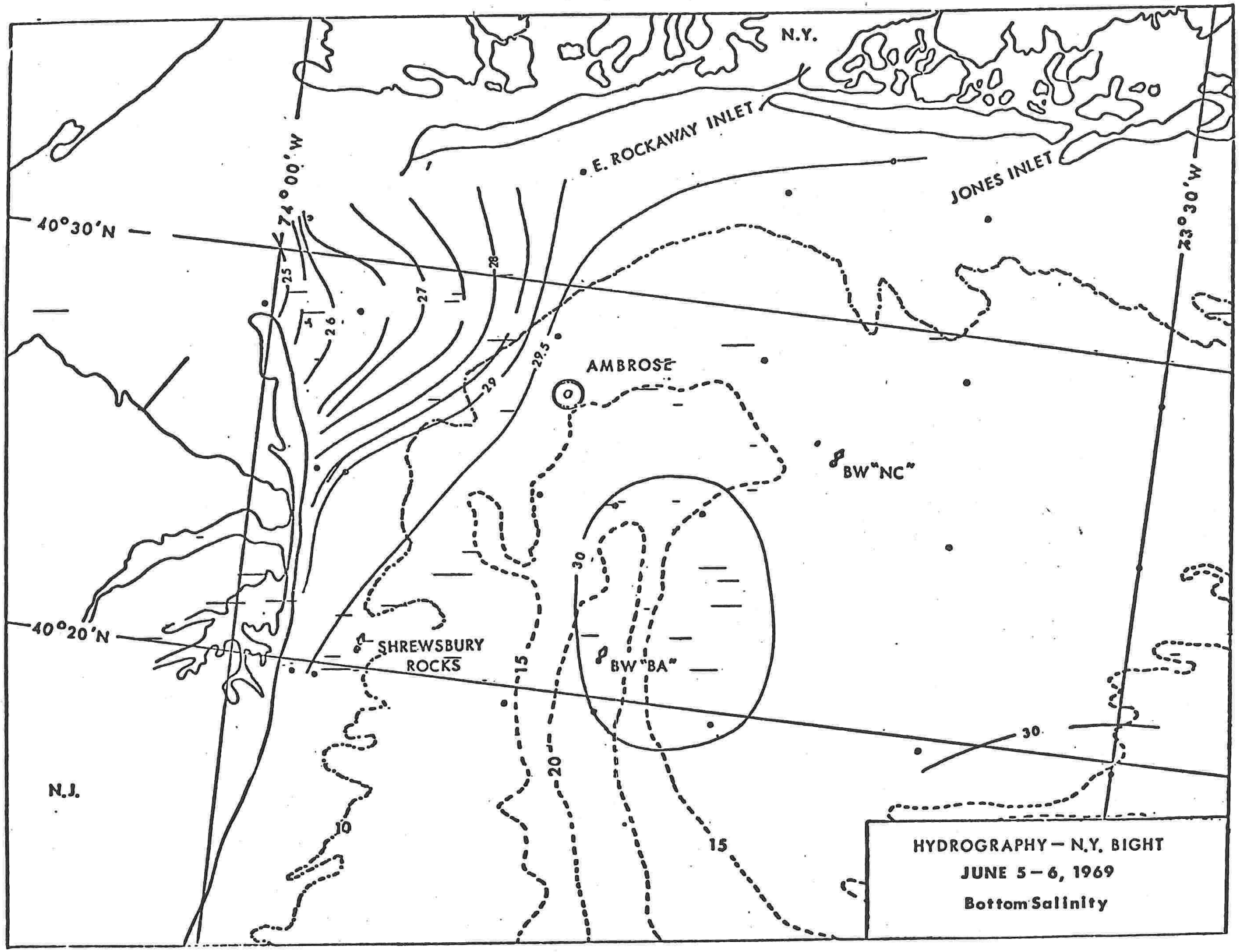

N.Y.
E. ROCKAWAY INLET
JONES INLET
74°00'W
73°30'W
40°30'N
40°20'N
25
26
27
28
29
29.5
AMBROSE
BW"NC"
BW"BA"
SHREWSBURY
ROCKS
30
15
20
10
N.J.
HYDROGRAPHY — N.Y. BIGHT
JUNE 5 – 6, 1969
Bottom Salinity

FIGURE 21

FIGURE 22

Monthly surface and bottom temperatures (Pearce, 1969)

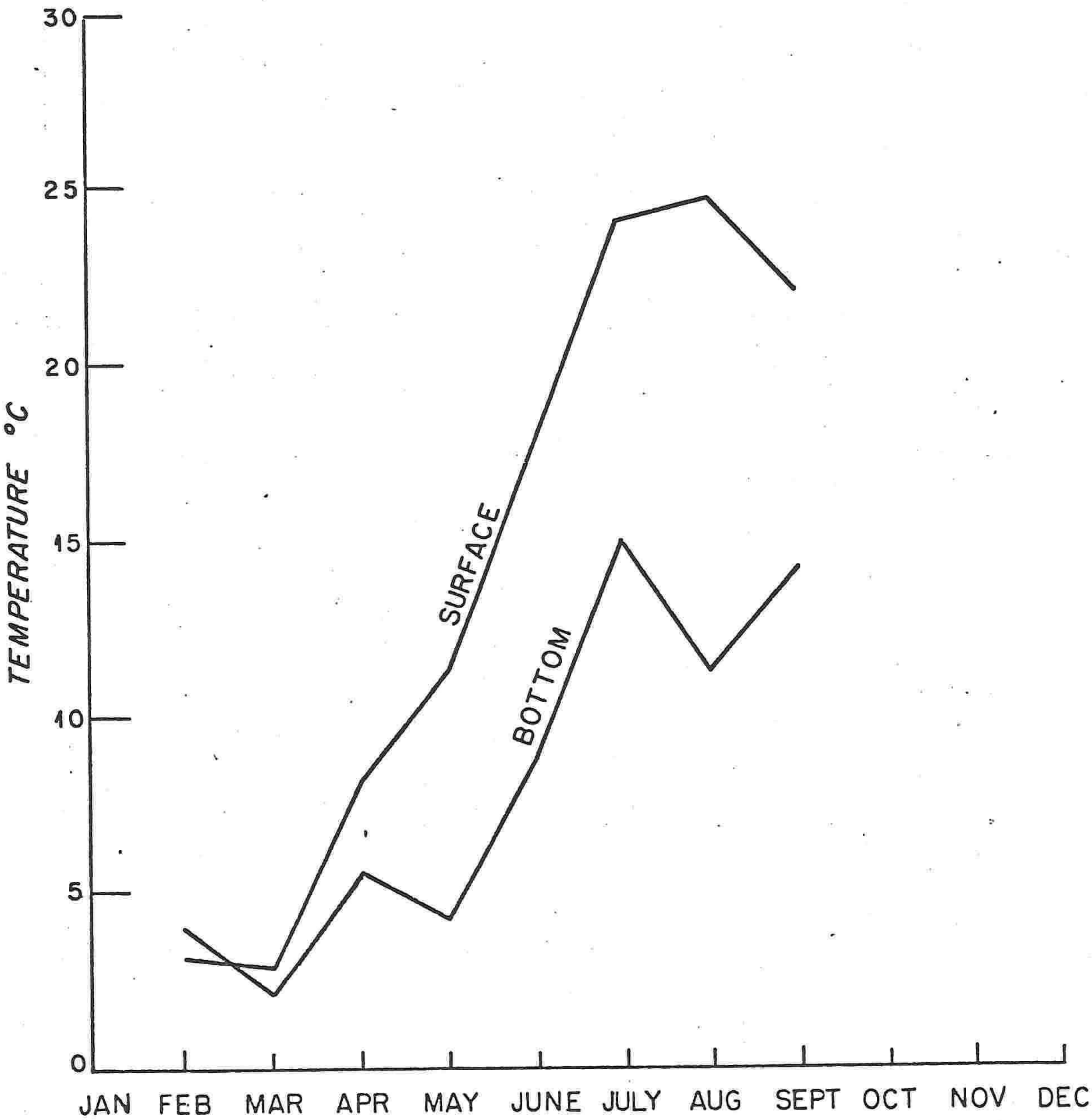
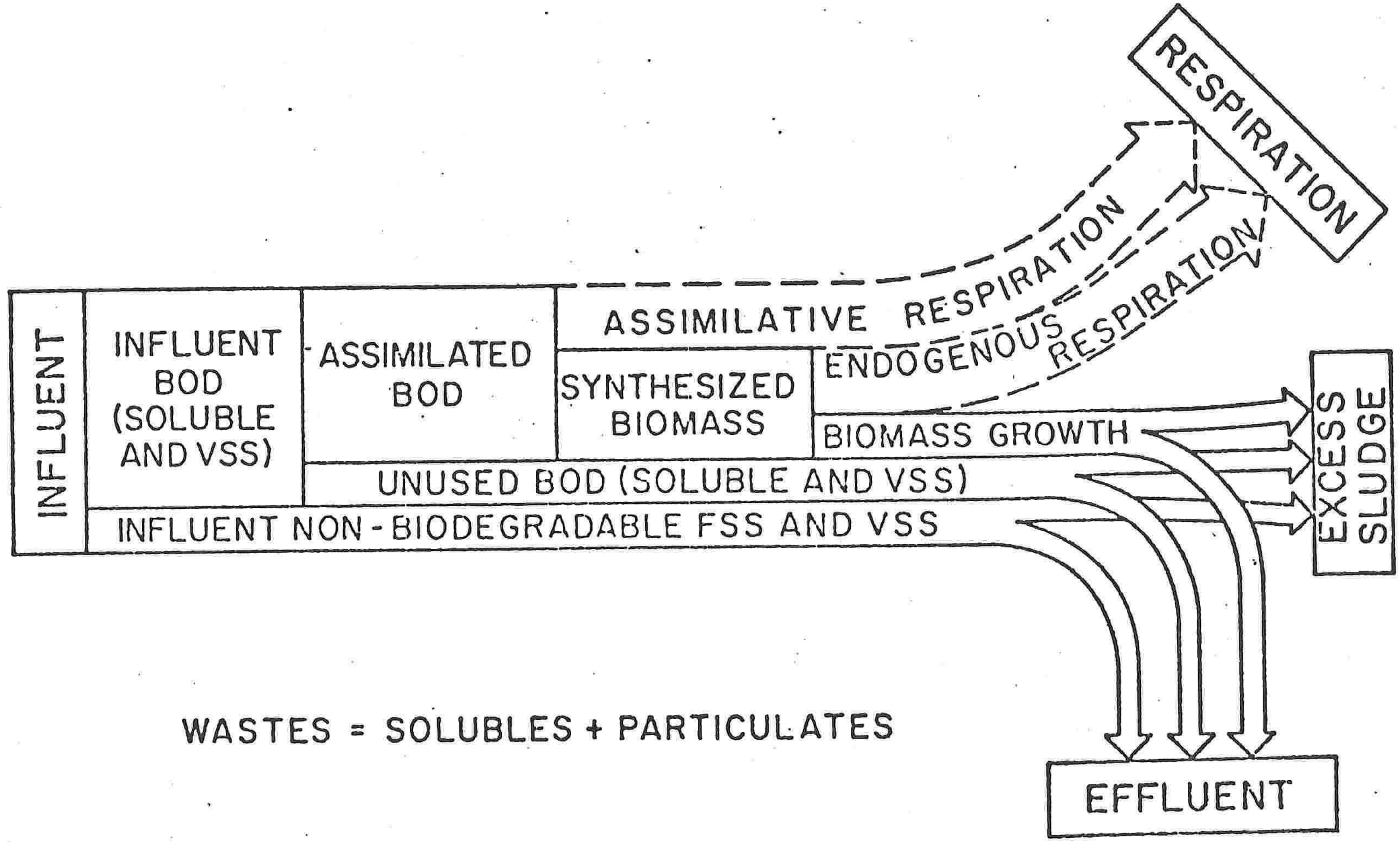

TEMPERATURE °C
30
25
20
15
10
5
0
SURFACE
BOTTOM
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC

FIGURE 22

FIGURE 23

METABOLISM AND PROCESS REACTIONS

M.J. Stewart, Ont. Ind. Waste Conf. Proc., No. 15, 93 (1968).



METABOLISM AND PROCESS REACTIONS

FIGURE 23

FIGURE 24

CONVENTIONAL ACTIVATED SLUDGE

M.J. Stewart, Ont.Ind.Waste Conf. Proc., No. 15, 93 (1968).

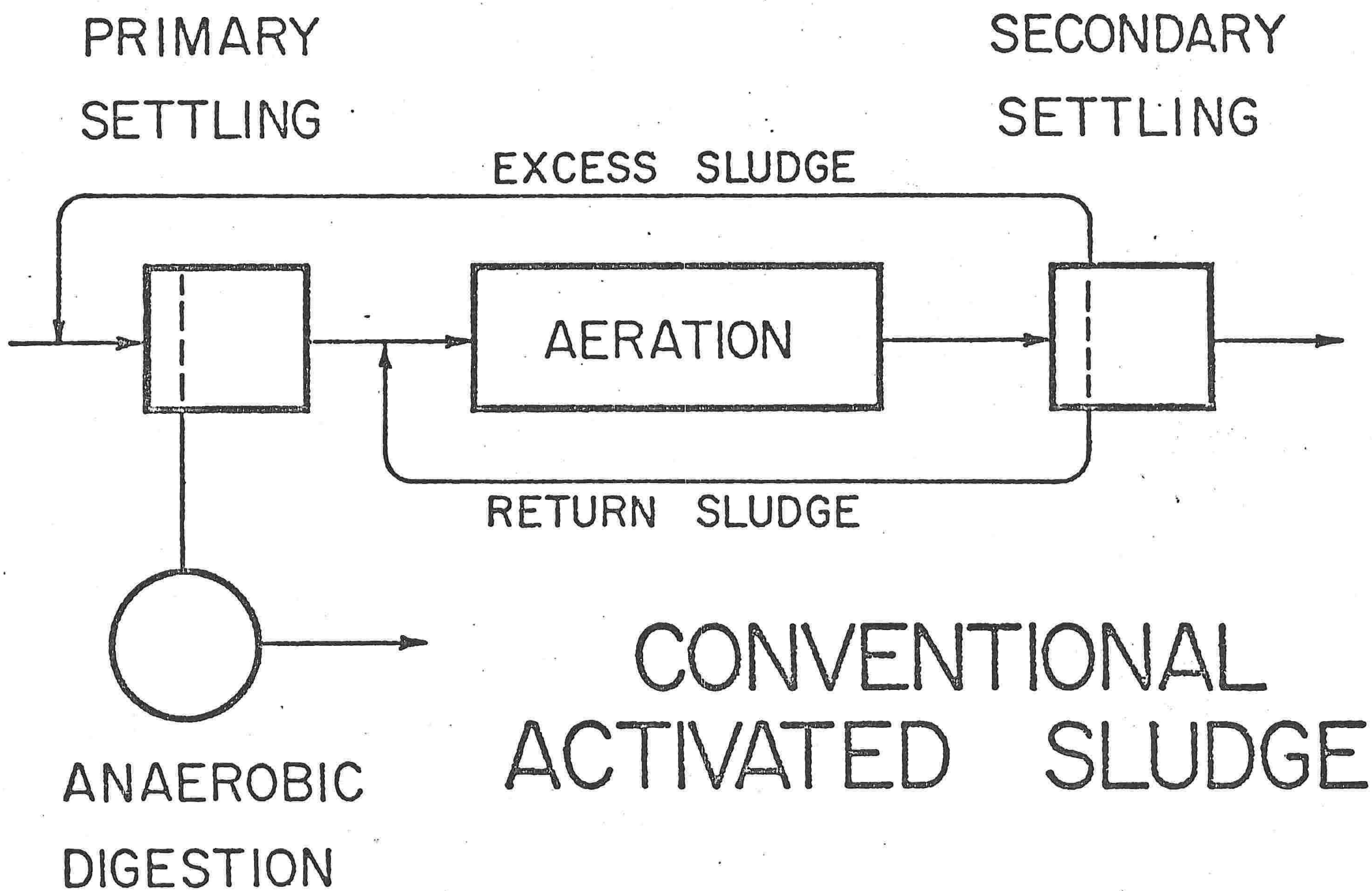

PRIMARY
SETTLING
SECONDARY
SETTLING
EXCESS SLUDGE
AERATION
RETURN SLUDGE
ANAEROBIC
DIGESTION
CONVENTIONAL
ACTIVATED SLUDGE

FIGURE 24

FIGURE 25

Sewer Treatment Flow Diagram

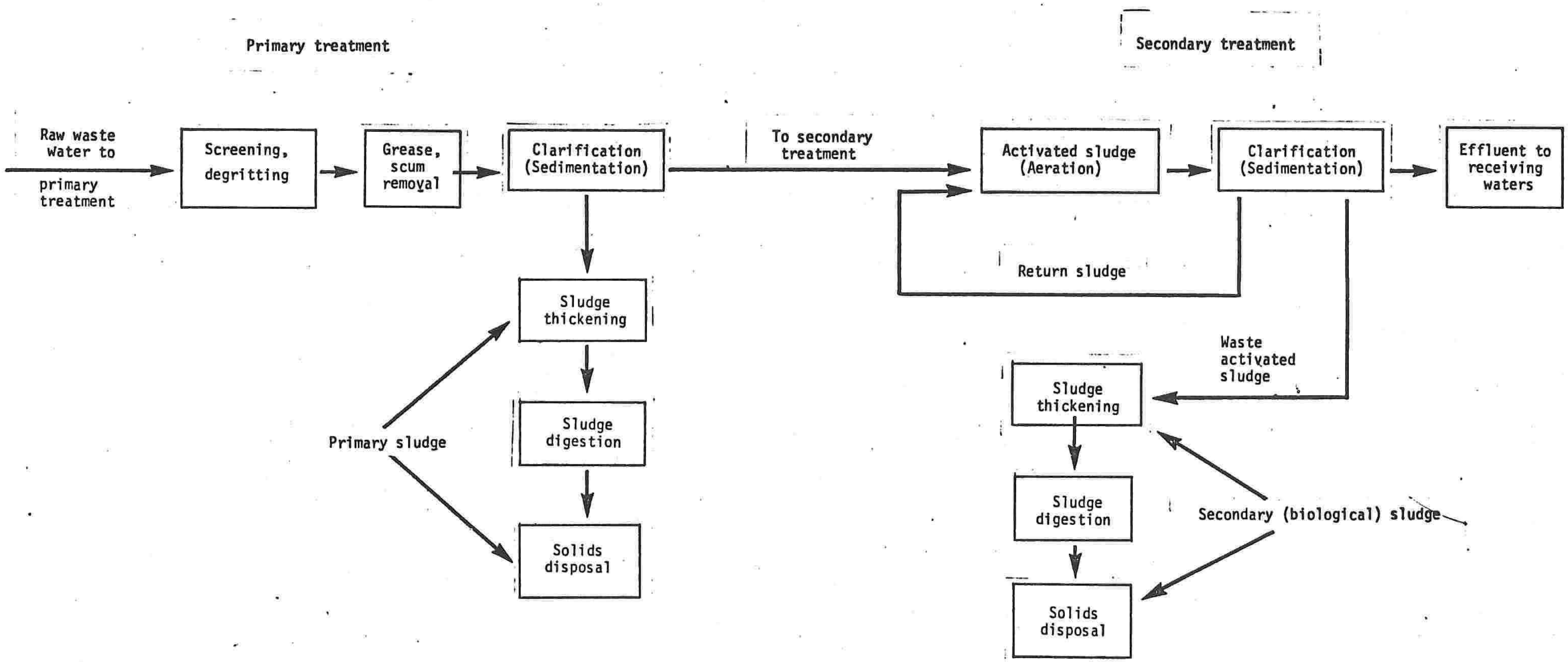

Primary treatment
Secondary treatment
Raw waste water to primary treatment
Screening, degritting
Grease, scum removal
Clarification (Sedimentation)
To secondary treatment
Activated sludge (Aeration)
Clarification (Sedimentation)
Effluent to receiving waters
Return sludge
Waste activated sludge
Sludge thickening
Sludge digestion
Solids disposal
Primary sludge
Sludge thickening
Sludge digestion
Solids disposal
Secondary (biological) sludge

FIGURE 25

FIGURE 26

The organic matter content of sediments in the New York Bight area showing the high concentration in the sewer sludge disposal site. The line extending seaward from the coast of New Jersey shows where observations illustrated in the following figures were made. (Pearce, 1970).

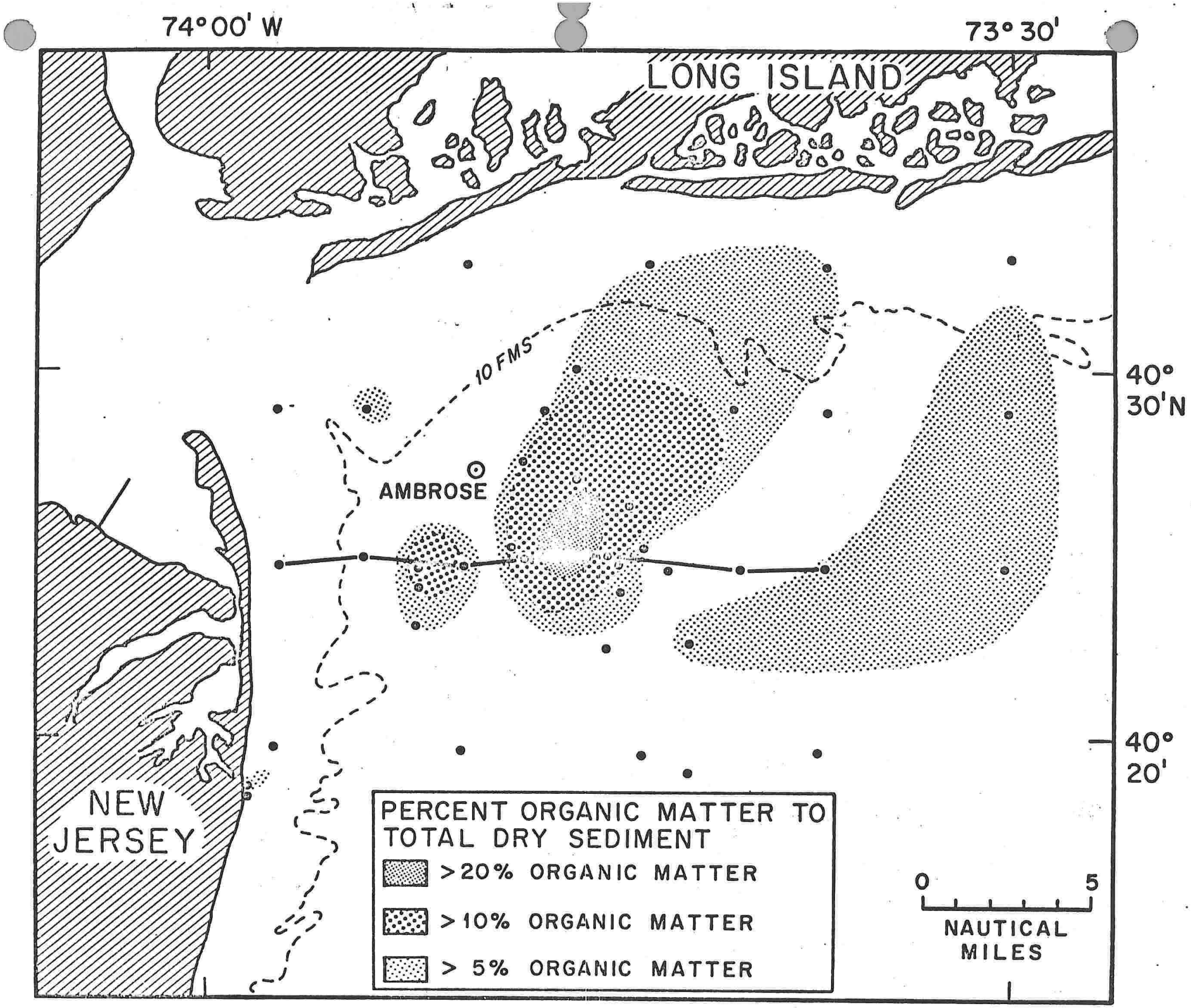

74°00' W
73°30'
LONG ISLAND
10 FMS
AMBROSE
40°
30'N
40°
20'
NEW
JERSEY
PERCENT ORGANIC MATTER TO
TOTAL DRY SEDIMENT
>20% ORGANIC MATTER
>10% ORGANIC MATTER
> 5% ORGANIC MATTER
0
5
NAUTICAL
MILES

FIGURE 26

FIGURE 27

Oxygen (Dissolved) PPM
Bottom, August, 1969

(Pearce, 1969)

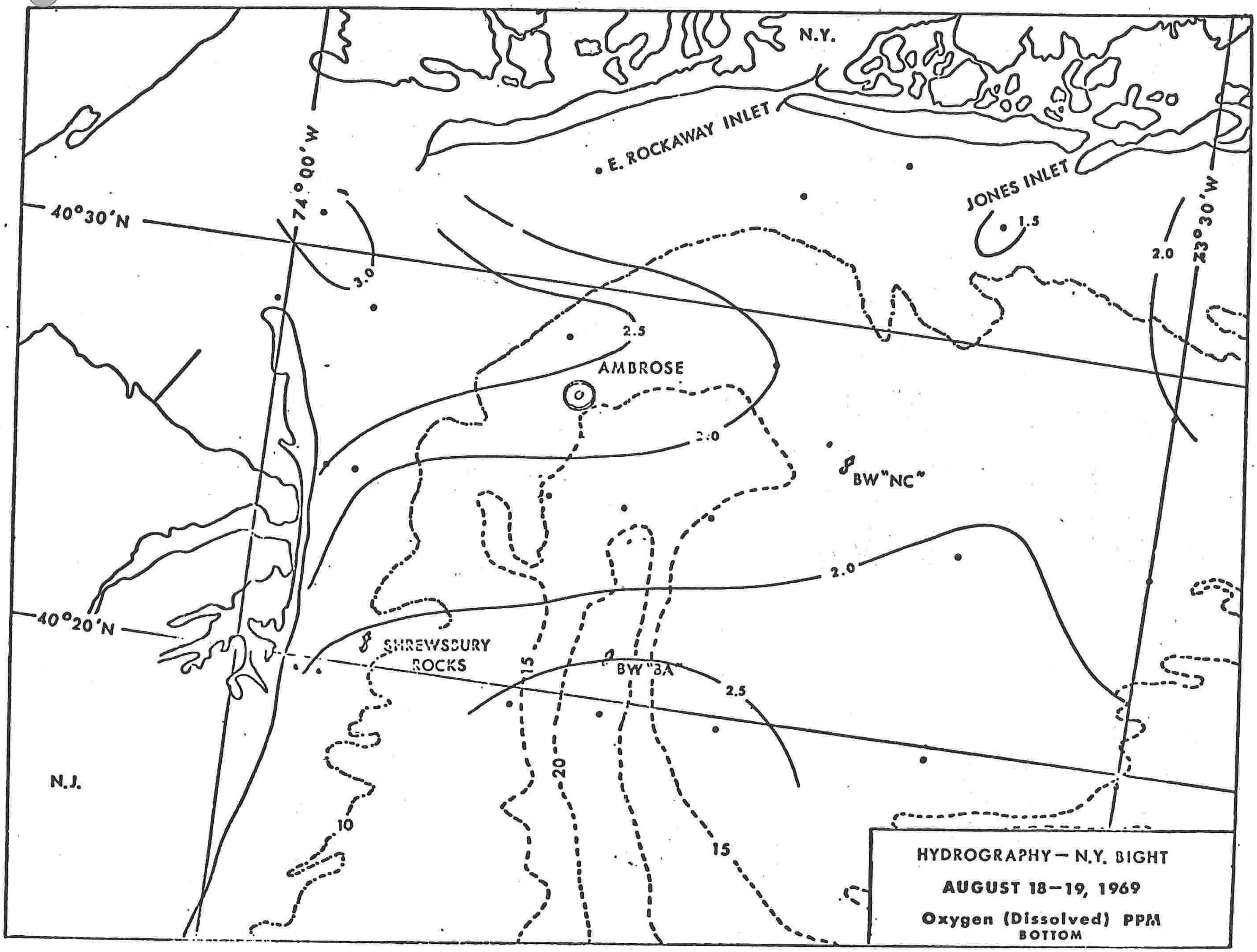
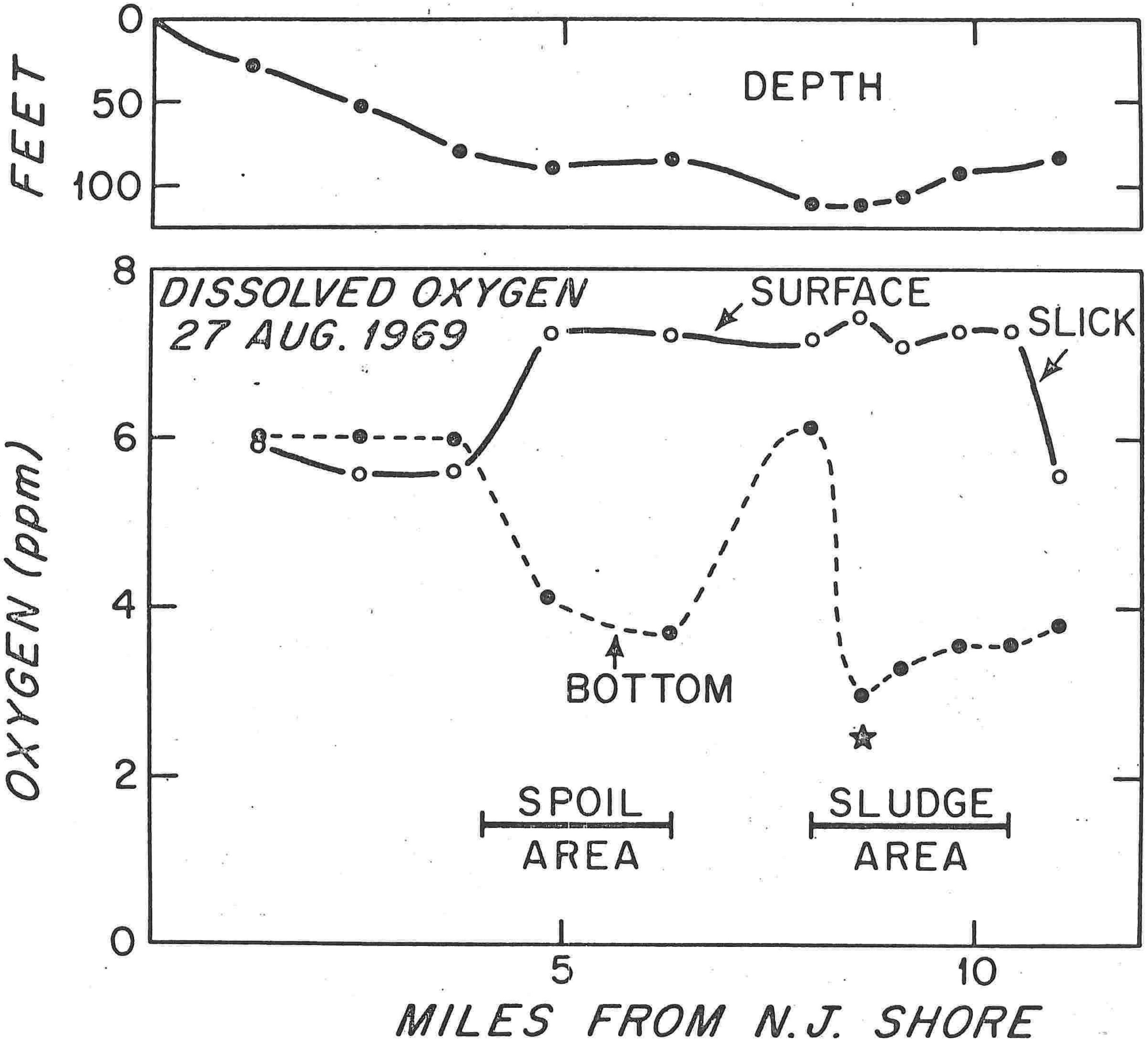

N.Y.
E. ROCKAWAY INLET
JONES INLET
1.5
2.0
23°30'W
74°00'W
40°30'N
40°20'N
3.0
2.5
AMBROSE
2.0
BW"NC"
2.0
SHREWSBURY ROCKS
BW"3A"
2.5
15
20
15
10
N.J.
HYDROGRAPHY — N.Y. BIGHT
AUGUST 18–19, 1969
Oxygen (Dissolved) PPM
BOTTOM

FIGURE 27

FIGURE 28

The water depth and the oxygen content of surface water and water three feet off the bottom in a section extending seaward from the coast of New Jersey. The surface slick indicated may reflect a recent disposal. (Ketchum, 1970).



FEET
0
50
100
DEPTH
OXYGEN (ppm)
8
6
4
2
0
DISSOLVED OXYGEN
27 AUG. 1969
SURFACE
SLICK
BOTTOM
SPOIL
AREA
SLUDGE
AREA
5
10
MILES FROM N.J. SHORE

FIGURE 28

FIGURE 29

The variation with time of oxygen in the surface water and water three feet off the bottom at a station located in the center of the sewer sludge disposal site. The location is indicated by a star in Figure 28. (Pearce, 1970).

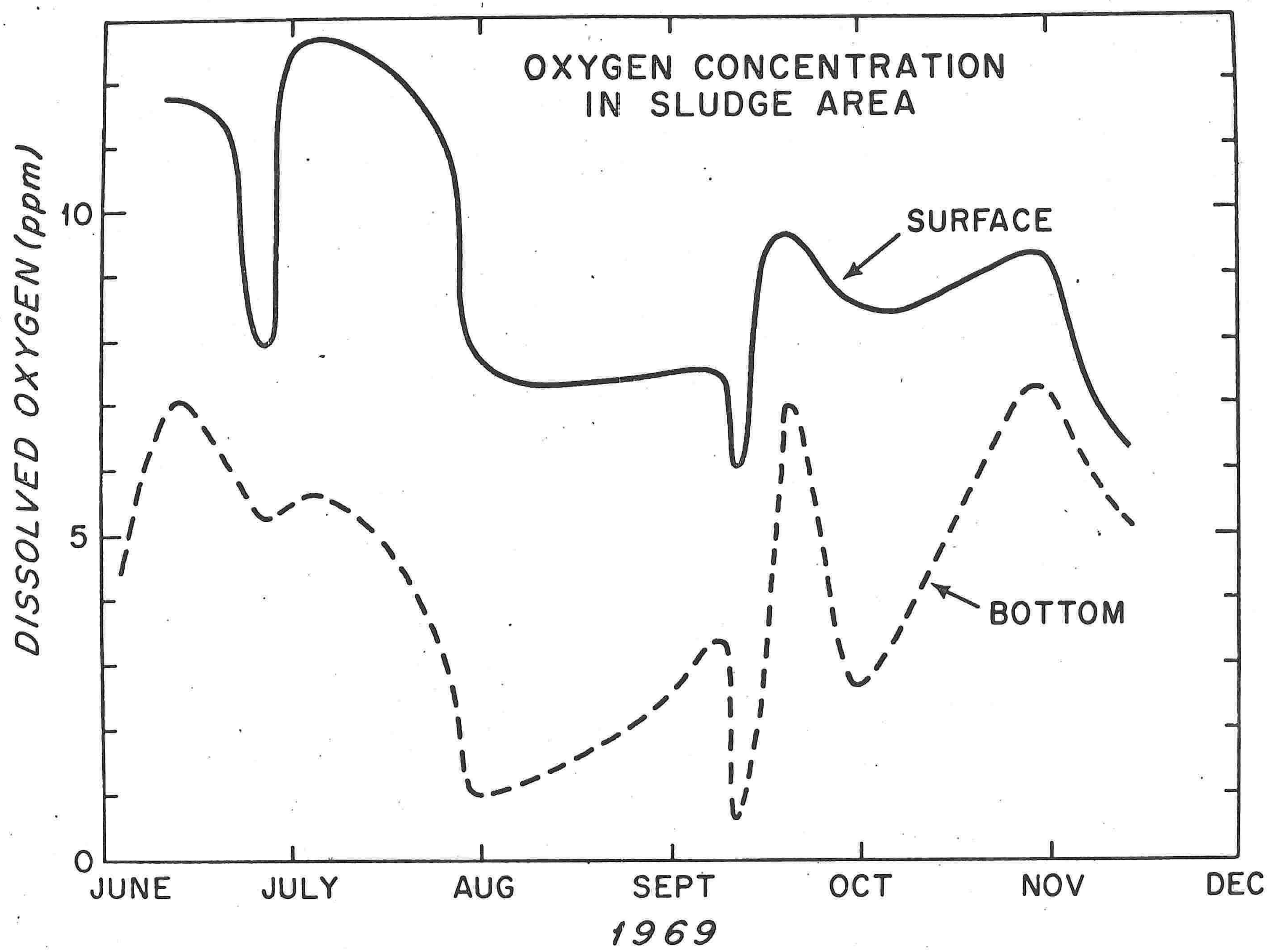

OXYGEN CONCENTRATION
IN SLUDGE AREA
SURFACE
BOTTOM
DISSOLVED OXYGEN (ppm)
10
5
0
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
1969

FIGURE 29

FIGURE 30

Heavy Metal Concentrations

(ppm, 2% HNO_3 extraction) (Pearce, 1969)

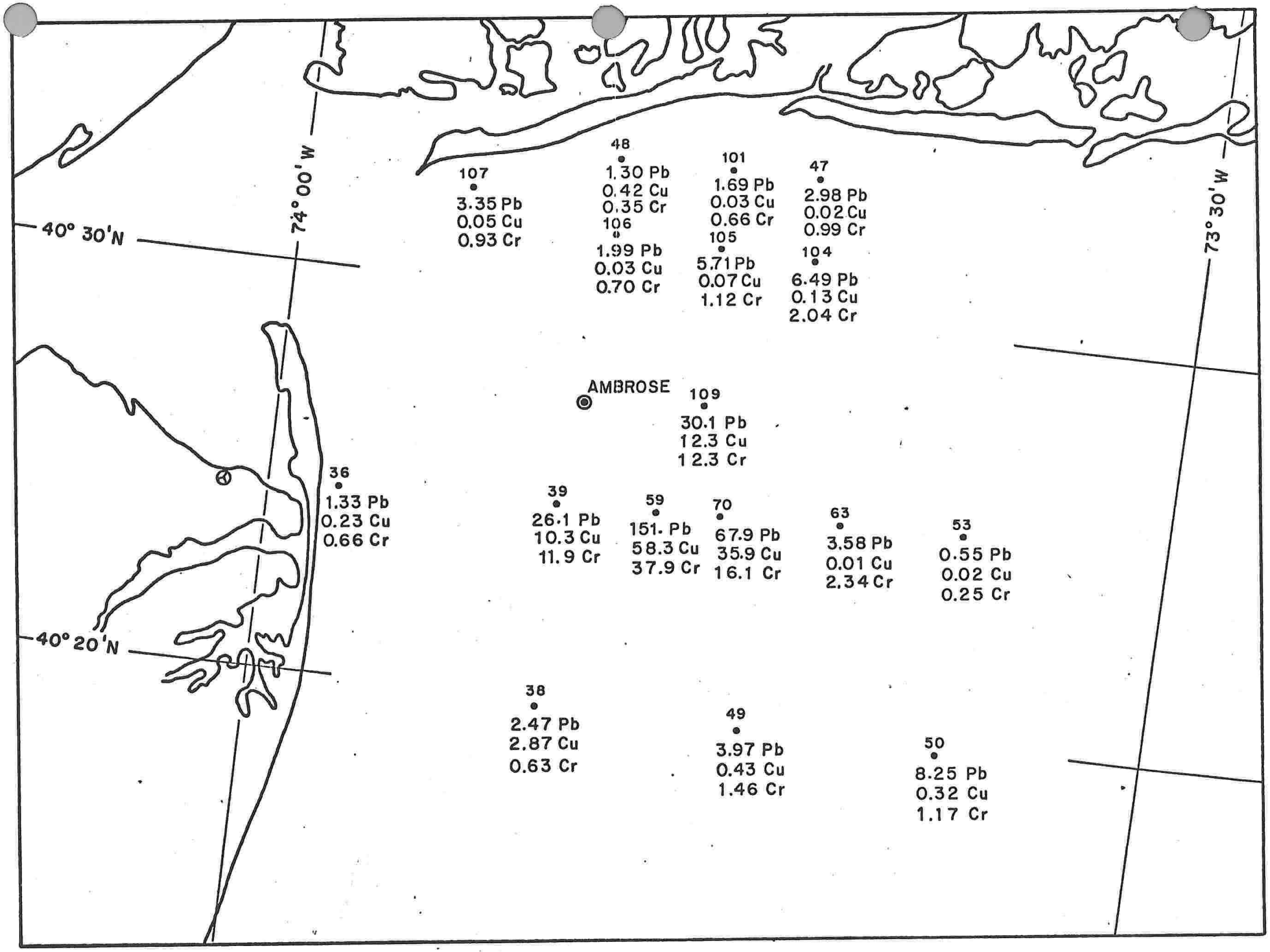
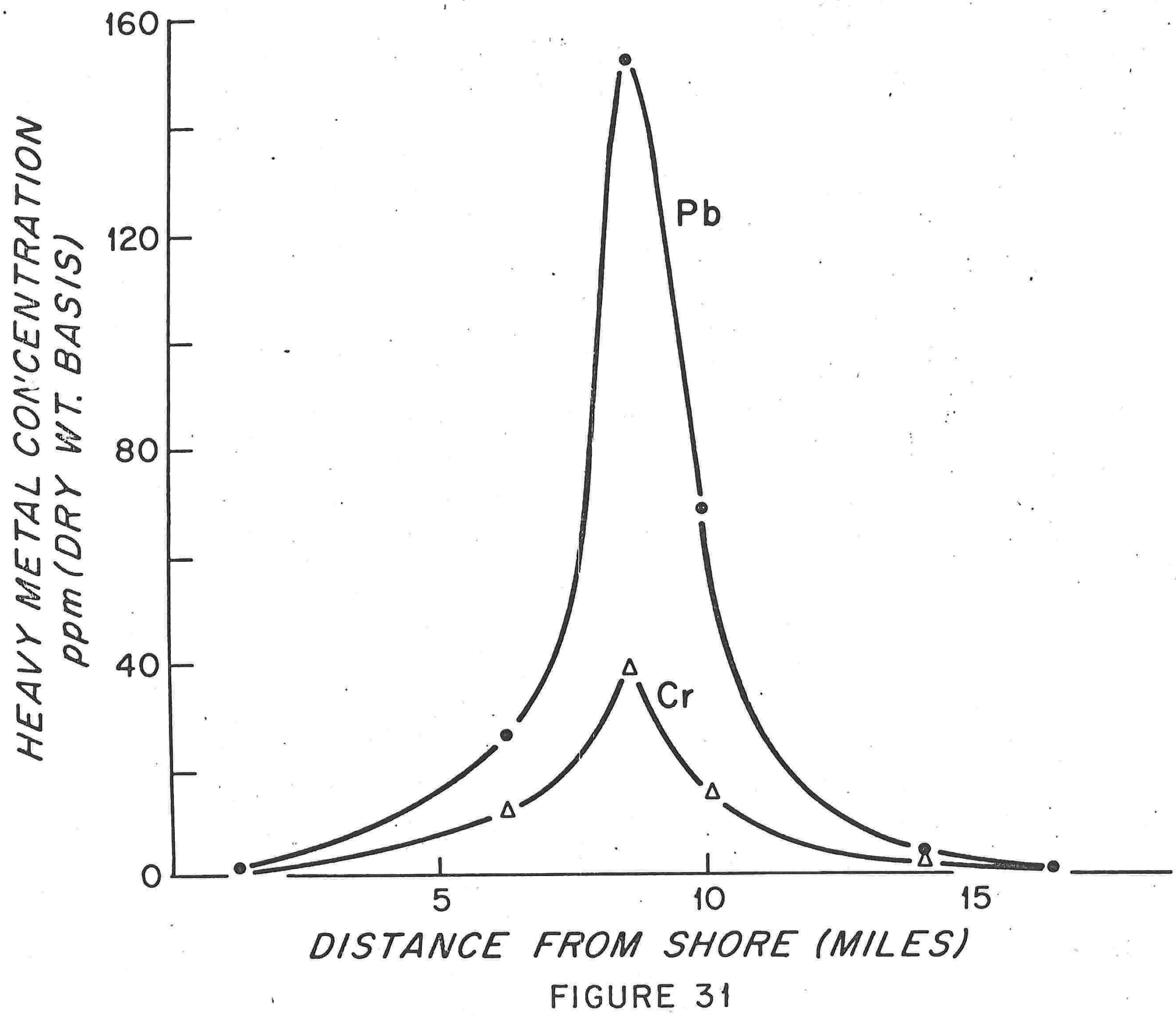

74° 00' W
73° 30' W
40° 30' N
40° 20' N
AMBROSE
107
3.35 Pb
0.05 Cu
0.93 Cr
48
1.30 Pb
0.42 Cu
0.35 Cr
106
1.99 Pb
0.03 Cu
0.70 Cr
101
1.69 Pb
0.03 Cu
0.66 Cr
105
5.71 Pb
0.07 Cu
1.12 Cr
47
2.98 Pb
0.02 Cu
0.99 Cr
104
6.49 Pb
0.13 Cu
2.04 Cr
109
30.1 Pb
12.3 Cu
12.3 Cr
36
1.33 Pb
0.23 Cu
0.66 Cr
39
26.1 Pb
10.3 Cu
11.9 Cr
59
151. Pb
58.3 Cu
37.9 Cr
70
67.9 Pb
35.9 Cu
16.1 Cr
63
3.58 Pb
0.01 Cu
2.34 Cr
53
0.55 Pb
0.02 Cu
0.25 Cr
38
2.47 Pb
2.87 Cu
0.63 Cr
49
3.97 Pb
0.43 Cu
1.46 Cr
50
8.25 Pb
0.32 Cu
1.17 Cr

FIGURE 30

FIGURE 31

The concentration of lead and chromium in the sediments along a section extending seaward from the coast of New Jersey. (Pearce, 1970).



HEAVY METAL CONCENTRATION
ppm (DRY WT. BASIS)
160
120
80
40
0
Pb
Cr
5
10
15
DISTANCE FROM SHORE (MILES)

FIGURE 31

FIGURE 32

The abundance of nematodes in bottom deposits along a section extending seaward from the coast of New Jersey. (Pearce, 1970).

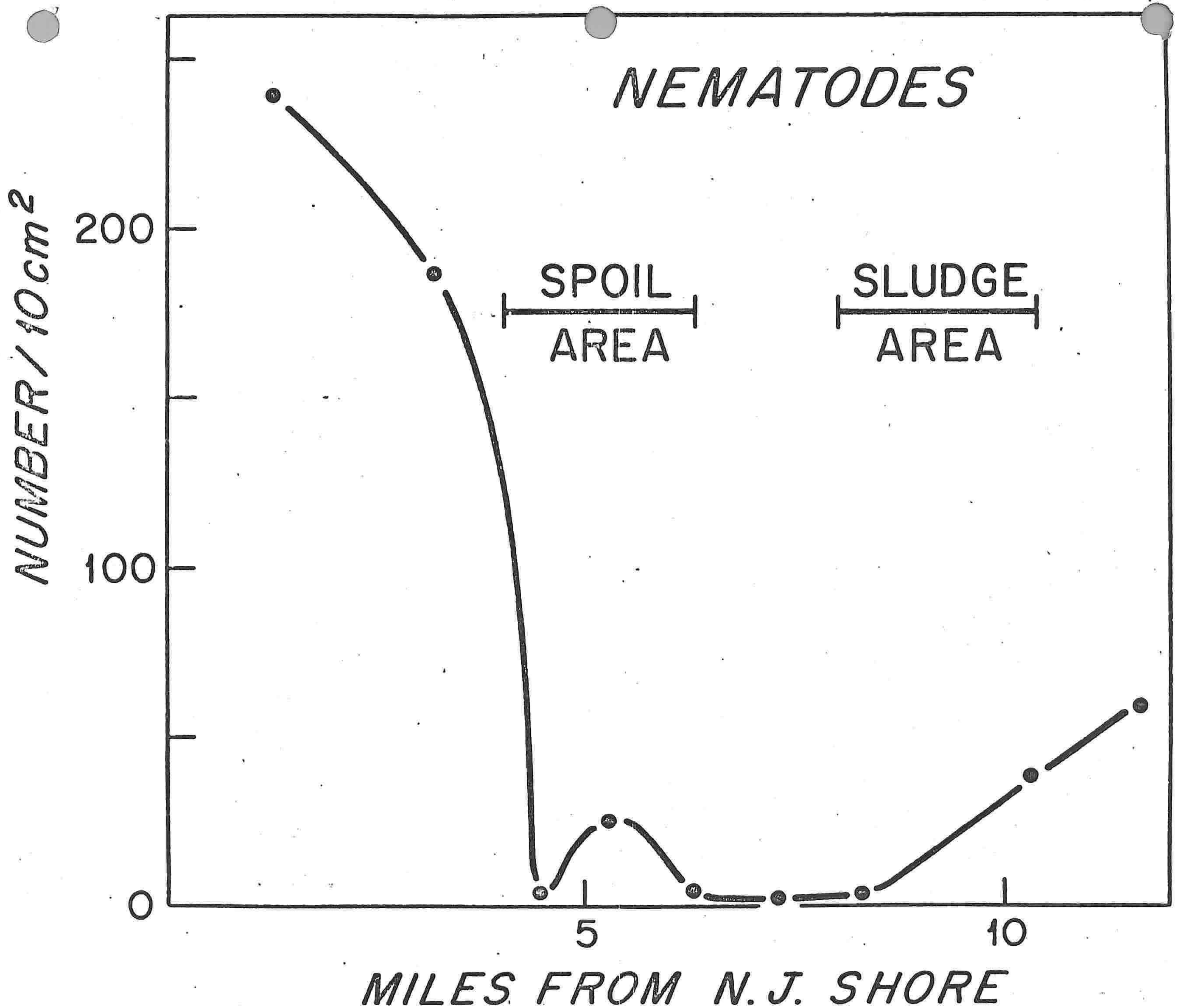

NEMATODES
SPOIL AREA
SLUDGE AREA
NUMBER / 10 cm²
200
100
0
5
10
MILES FROM N.J. SHORE

FIGURE 32

FIGURE 33

Zooplankton Population
(Average of surface, middle, and bottom counts) (Pearce, 1969)

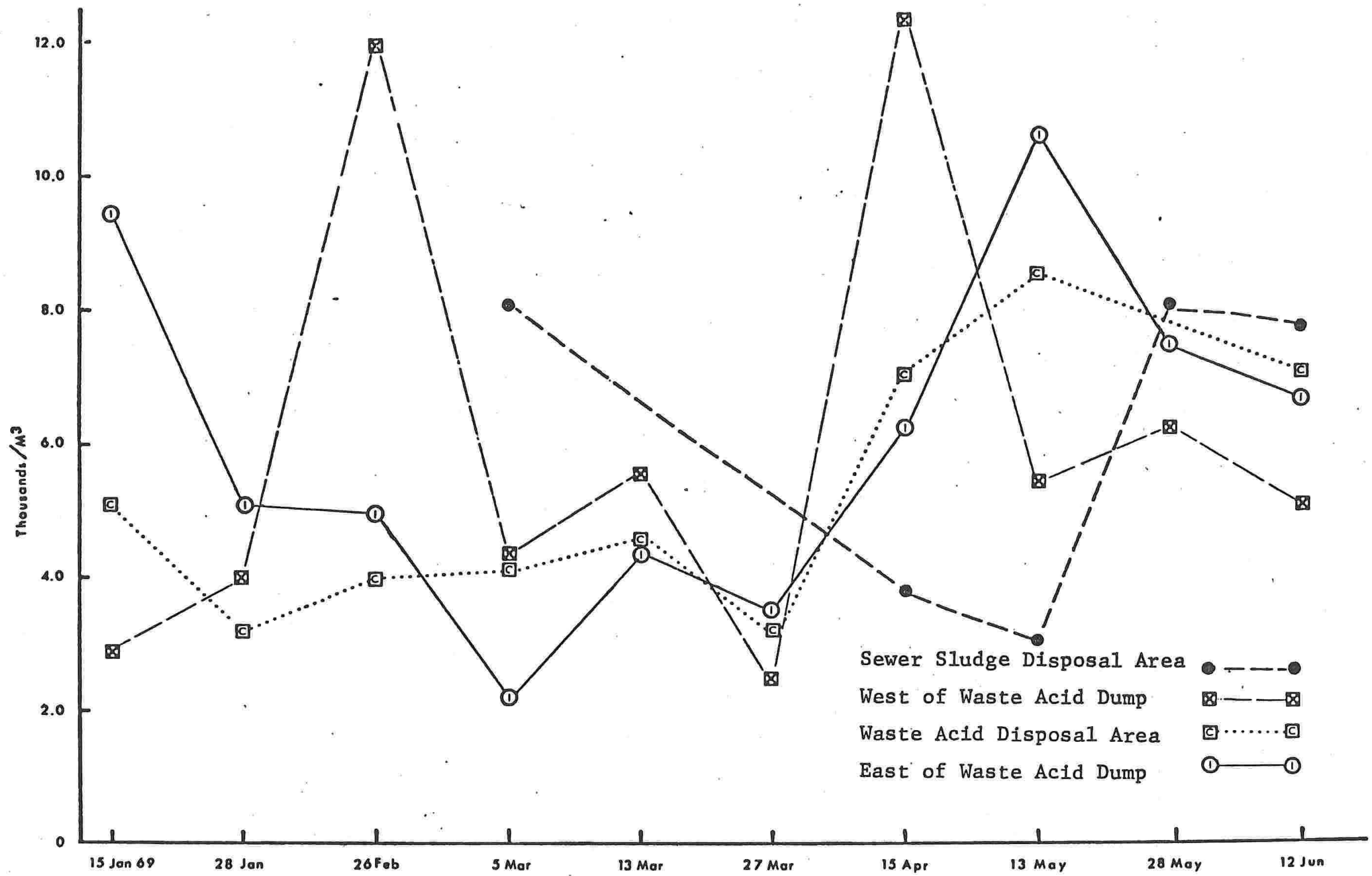

Thousands/M3
12.0
10.0
8.0
6.0
4.0
2.0
0
15 Jan 69
28 Jan
26Feb
5 Mar
13 Mar
27 Mar
15 Apr
13 May
28 May
12 Jun
Sewer Sludge Disposal Area
West of Waste Acid Dump
Waste Acid Disposal Area
East of Waste Acid Dump

FIGURE 33

FIGURE 34

Total Pounds Cod and Flounder (Blackback and Fluke)
Caught by Areas 1,2,3,5 New York Landings for Years 1961-69

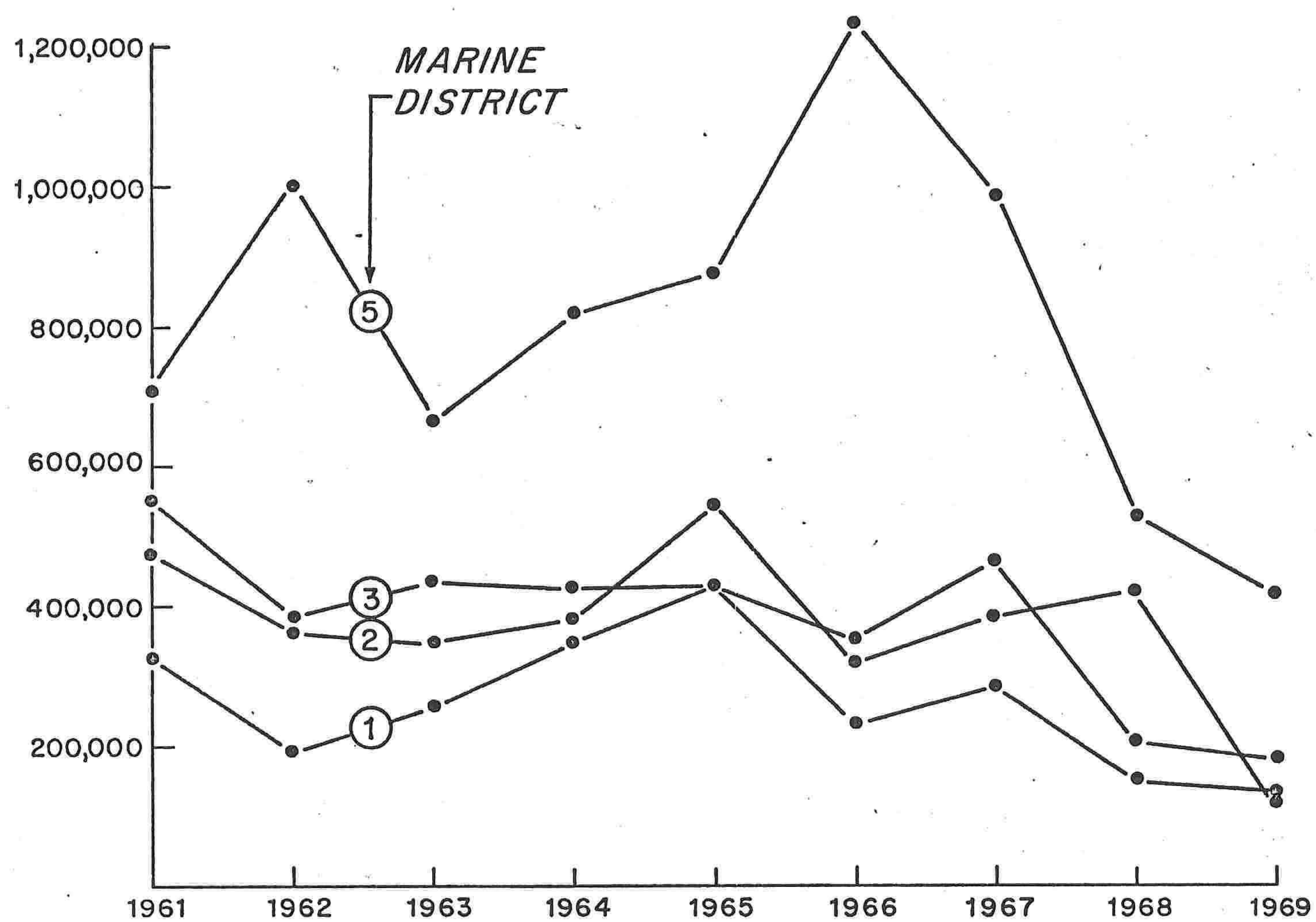

MARINE
DISTRICT
1,200,000
1,000,000
800,000
600,000
400,000
200,000
1961
1962
1963
1964
1965
1966
1967
1968
1969
5
3
2
1

FIGURE 34

FIGURE 35

New York Marine District

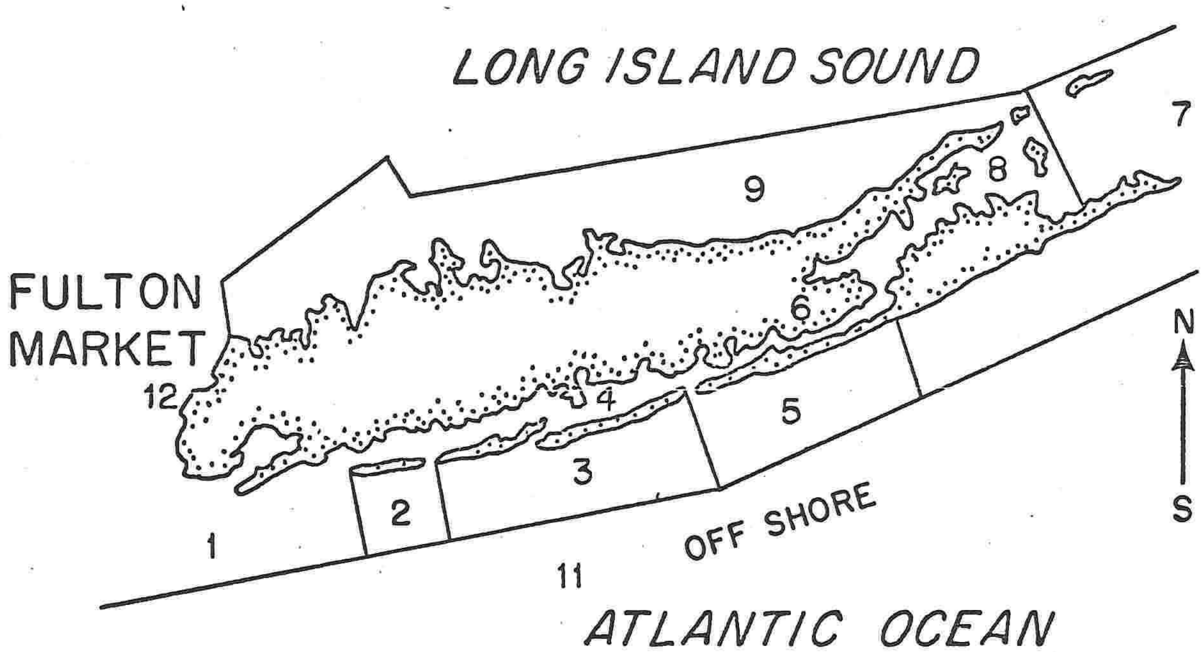

LONG ISLAND SOUND
7
9
8
FULTON
MARKET
6
12
4
5
3
2
1
OFF SHORE
11
N
S
ATLANTIC OCEAN

FIGURE 35

FIGURE 36

Profile of densities of coliform organisms about one mile off shore, vicinity of Hyperion outfall on Jan. 12, 1956. (Lawrence, 1958)

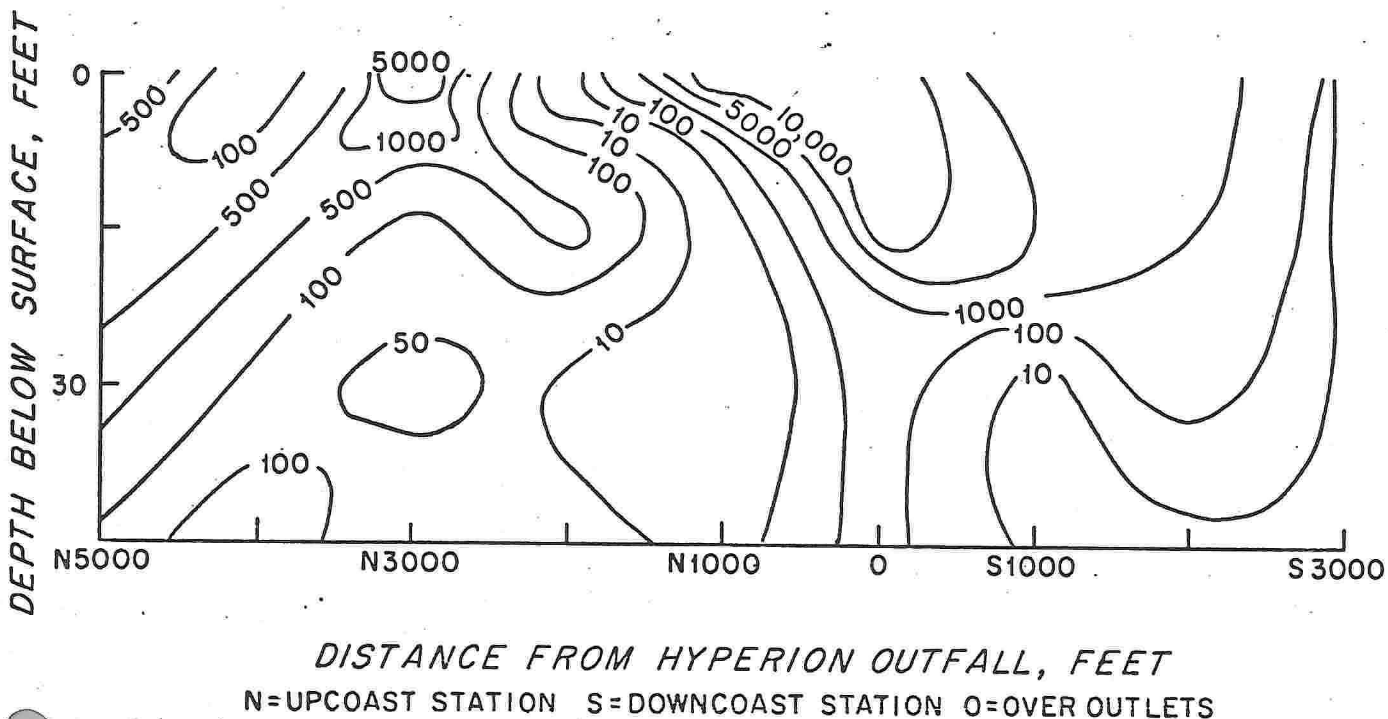

DEPTH BELOW SURFACE, FEET
0
30
5000
500
100
1000
500
500
10
10
100
10
100
5000
10,000
100
50
100
10
1000
100
10
N5000
N3000
N1000
0
S1000
S3000
DISTANCE FROM HYPERION OUTFALL, FEET
N=UPCOAST STATION S=DOWNCOAST STATION O=OVER OUTLETS

FIGURE 36

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